STATEMENT
AND
ENGINEERING REPORT
BY THE
HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO

SUBMITTED TO THE

INTERNATIONAL JOINT COMMISSION

RESPECTING THE

PROPOSAL TO DEVELOP

THE

ST. LAWRENCE RIVER

1921

TORONTO
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OF ONTARIO

Hon. Sir Adam Beck, Kt., LL.D., M.L.A.	*Chairman*
Hon. J. R. Cooke, M.L.A.	*Commissioner*
W. W. Pope, Esq.	*Secretary*
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AN EXPLANATION

The national and international importance to the citizens of the Dominion of Canada and of the United States of the proposed development of the St. Lawrence river in the joint interests of navigation and of water power is a subject which, for many years, has engaged the earnest attention of the Hydro-Electric Power Commission of Ontario.

When the International Joint Commission, in January, 1920, was empowered by the two Governments which it represents to make a special investigation respecting the improvement of the St. Lawrence river, the Hydro-Electric Power Commission of Ontario arranged that the information which it already possessed should be supplemented with information resulting from additional research and that the whole should be reduced to the form of a report with the object of aiding the International Joint Commission in its important investigation. This plan was pursued and the report thus contemplated was duly filed with the International Joint Commission.

It will, of course, be appreciated that the Hydro-Electric Power Commission confines its discussion and representations essentially to the international portion of the St. Lawrence river, it being the only portion of the river in which the Commission, as trustee for the municipalities of the province of Ontario, possesses a direct interest by virtue of the water power developable from the water not required for navigation purposes.

It was hoped and, indeed, confidently expected that the International Joint Commission would publish its report accompanied—probably as appendices—by such other important reports as would be filed with the Commission in connection with the St. Lawrence investigation. This course, however, was not followed and, so far as can be ascertained, the International Joint Commission, except as a document by one of the departments of the United States Federal Government at Washington, D.C., has not even printed its own final report as deposited with the two Governments.

The Hydro-Electric Power Commission is deeply interested in doing everything possible to facilitate the development, at the earliest possible date, of the water power belonging to the province of Ontario in the international section of the St. Lawrence river. Inasmuch as there appears to have been some misunderstanding respecting the position taken by the Hydro-Electric Power Commission with regard to the St. Lawrence River proposals, the Commission has concluded it desirable in the general public interest to itself publish its report and the accompanying plans as filed in 1921 with the International Joint Commission, believing that in so doing, an important contribution to the problem under discussion will be available for the consideration of all who are interested in furthering the development of the St. Lawrence river.

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To the Members of the International Joint Commission

Gentlemen:

You have presented for the special attention of the Hydro-Electric Power Commission of Ontario certain subjects closely related to the proposed development of the St. Lawrence river to the end that its waters may most beneficially be used in the interests of the people of Canada and of the United States for purposes of navigation and of power.

You have requested that the results of the experience of the Hydro-Electric Power Commission gained in the development, transmission, and distribution of hydro-electrical energy be assembled for your consideration. Accordingly the Commission has prepared this *Statement* which is accompanied by an *Engineering Report* with Plans and Appendices containing engineering and other data specially assembled and analyzed by the engineers of the Commission.

This *Statement* deals with the subject of power, but in order to avoid any misapprehension and to anticipate any suggestion that due consideration has not been given to the claims of navigation in the St. Lawrence river,

the Commission desires at the outset to emphasize that full account has been taken of the needs of navigation and in all plans for the proposed development of the water power of the St. Lawrence river provision has been made for the physical needs of whatever navigation improvements the International Joint Commission may recommend.

The economics of the improvement of navigation in the St. Lawrence is a phase of the problem which the International Joint Commission has taken special means to determine, and consequently the Hydro-Electric Power Commission has not specially dealt with this subject. The Commission's researches, however, have conclusively demonstrated that hydro-electric development of the St. Lawrence river can be carried out in such manner as to justify its development from the standpoint of power production alone, while at the same time providing that the physical structures required for power shall embrace all features necessary to safeguard the present and future requirements of improved navigation.

Demand for Power

So far as power development in the St. Lawrence river is concerned, the problem resolves itself into the question: "Can the large quantities of power which may be made available from the St. Lawrence river be beneficially and economically absorbed to the mutual advantage of the citizens of each of the countries interested?" The Commission hopes to demonstrate to your satisfaction the basis of its belief that the end suggested by this question can be achieved.

The Hydro-Electric Power Commission of Ontario has made no marked stride in its growth without encountering strong opposition. Frequently the Commission has had to anticipate the need of, and to proceed to make available, large quantities of electrical energy, years prior to any tangible demonstration that the energy would all be absorbed. Against such procedure, protest has been raised which corresponds to the contention one hears from various quarters against the policy of preparing now for the development of the water powers of the St. Lawrence river.

When the Hydro-Electric Power Commission began marketing power to meet the growing municipal and industrial needs of southwestern Ontario, the contract it made for the delivery of 100,000 horsepower was referred to as an evidence of ill-advised procedure but within five years the whole 100,000 horsepower had been marketed. As additional power was provided there were always those—and they were not without influence—who proclaimed that the limits of sound judgment had been exceeded. When the Commission found it desirable to purchase the Ontario Power Company's Niagara plant and the Central Ontario water-power system at an outlay involving about thirty-eight million dollars, the cry was raised that such

expenditure was improvident and could never be justified. It was challenged, "how can such large quantities of power be marketed in the districts available?" In 1914, just prior to the War, it was contended that the Commission would be unable, within a reasonable period, to market its unsold power. The vital part which this power subsequently played in the War does not need to be enlarged upon at this time. After the War however it was confidently asserted by parties whose opinions carried weight, that the dropping of the War power loads would surely cripple the operations of the Commission, but it soon transpired that all these dropped loads were quickly re-absorbed and the Commission found itself again wrestling with problems arising from an actual shortage of electrical energy.

Notwithstanding the fact that opposition of this kind was being encountered, the Commission, basing its outlook upon its knowledge of underlying governing factors, felt it necessary as early as 1913 to provide for still larger power demands by preparing plans for a new development at Niagara Falls. These provisions have since taken the form of the new Queenston-Chippawa power development which will soon be supplying power and is designed to furnish, ultimately, 550,000 horsepower. This output the Commission expects to see absorbed as it becomes available for commercial use.§

Future Demands Must be Anticipated

Now, the Commission draws attention to these facts—and assuredly they are striking facts—in order to emphasize to the International Joint Commission that many opinions, presumably of weight, have been entertained and freely expressed, with respect to hydro-electrical problems, which opinions are absolutely at variance with the forehanded policy that must be held and acted upon if future power demands are to be anticipated and adequately met. The Hydro-Electric Power Commission, from time to time, has weighed comments and criticisms such as have just been instanced, and finding that they have had their origin mainly in self-interest and ignorance of the facts or in other like conditions, has been compelled simply to ignore all such views and to proceed along lines which were believed justified by sound analyses of the basic facts at hand. In so doing the Commission has found that the markets for hydro-electrical energy have actually materialized in

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§See footnote §§§ on page 7.

Note: In preparing for the printer the copy of the original manuscript of this Report as submitted to the International Joint Commission, a few instances were observed where the reader would be aided by having certain information that has become available since the year 1921 when the Report was submitted to the International Joint Commission. Consequently, a few footnotes have been supplied. The supplementary notes thus added are designated by the symbol §.

a manner which has more than justified the decisions made in pursuance of this policy.§

Growth of Commission's Markets

The growth of the operations of the Hydro-Electric Power Commission has been remarkable. From supplying twelve municipalities in 1910 from a single transmission system its operations have expanded until now in 1921, from eleven distinct systems, the Commission is supplying under contract 280 municipalities and in addition numerous large corporations.

Since commencing operations the Commission and municipalities have purchased twenty-one water powers, thirty generating plants, and sixty distribution systems, and yet in not one instance has it been necessary to take advantage of the Commission's powers of expropriation under the legislation provided for such contingencies,—a fact which testifies to the actual consummation of the Commission's desire to deal fairly with existing interests.

The various systems owned or operated by the Commission for the participating municipalities are as follows: Niagara, Severn, Wasdells, St. Lawrence, Ottawa, Thunder Bay, Eugenia, Muskoka, Northern Ontario (Nipissing), Central Ontario, and Rideau systems.§§

The bounds of each system are determined by the geographical relationship of the various municipalities to their best source of power supply. Each system is separately organized and independently operated upon its own basis just as though it were the only system in existence. Of course where power may profitably be transmitted from one system to another, such transference may take place, but in these instances the power is actually sold to the receiving system and appears as a charge against its operations, and as a corresponding credit to the system supplying the same.

The Commission now supplies power under contract, directly and indirectly to 236 urban municipalities, including 22 cities, 77 towns and 137 villages, and in addition is supplying approximately 10,000 suburban consumers and over 2,000 farms in 44 townships. At present there are before the Commission 180 additional township applications for rates, etc., with the idea of securing electrical service.§§§

In 1910, there was an aggregate expenditure for the operations of the Commission of $3,750,000. To date there has been a total expenditure

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§See NOTE on page 20.

§§For latest information re the Commission's systems consult the last—Seventeenth—Annual Report for 1924.

§§§On October 31, 1924, the number of urban municipalities served had increased to 255, including 23 cities, 84 towns and 148 villages. Suburban and hamlet consumers now number over 15,000 and over 5,000 farms are supplied in 132 townships.

directly made by the municipalities on account of their own local systems of over $27,000,000 and in addition an expenditure made, on their behalf by the Commission acting as their trustee, for generating plants, transmission lines, and stations to supply the power used by the municipalities, of $145,000,000 or a total investment of $172,000,000.§

In the conduct of these extensive operations, the Commission has been in most intimate touch with all phases of the generation, transmission and distribution of electrical energy, not only in Ontario, but throughout the world at large, and consequently the Commission feels at no disadvantage in making analyses and recommendations respecting the possible future marketing of St. Lawrence River power. It has, as a matter of fact, specially investigated this field, and believes that your Commission will best be aided towards the solution of its problem involving St. Lawrence power if, first, there be briefly traced the development of Ontario's hydro-electrical markets, which, in the short space of twelve years have reached a stage where a maximum load of over 300,000 electrical horsepower has been absorbed, and if, then, it be shown what justification there is for the belief that the great water powers of the St. Lawrence River may also be economically developed and absorbed in the public interest of both Canada and the United States.§§

Rapid Growth in Consumption

Although, as early as 1900, a few prominent business men in south-western Ontario commenced agitation looking towards the securing of power from Niagara Falls in order to meet the increasing demands of industrial centres at that time chiefly dependent for their power upon imported coal from the United States,§§§ it was not until 1903 that the Government of the province of Ontario authorized the appointment, by the various interested municipalities, of a Commission, to investigate and report upon the proposal that Niagara power be supplied for municipal and industrial purposes. The report being duly prepared showed that the proposition promised success. Consequently in 1906, the provincial Government created the Hydro-Electric Power Commission of Ontario to act on behalf of the Province as trustee for municipalities, and, in due course, legislation was passed empowering the Commission to act.

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§The later corresponding figures for the fiscal year of the Commission ending October 31, 1924, are, total expenditure made directly by the municipalities, $73,000,000; expenditure made on their behalf by the Commission, $182,000,000, or a total investment of $255,000,000.

§§In fifteen years about 750,000 electrical horsepower has been absorbed.

§§§Respecting the general fuel problem of Canada, consult the discussion upon this subject in the twenty-second volume (1922) of *The Canadian Annual Review*, Toronto, 1923, page 114, *et seq*, and particularly the extensive footnote on page 119, *ibid*, citing articles and addresses respecting various phases of the national and international aspects of Canada's fuel problem.

The following table indicates the growth in demand for hydro-electrical energy on the Commission's systems:

GROWTH IN DEMAND FOR HYDRO-ELECTRICAL ENERGY

(Hydro-Electric Power Commission of Ontario)

Year	Number of customers			Total loads for October	
	Urban municipalities	Townships	Total consumers	Ontario only	Ontario plus exported power
				horsepower	horsepower
1910	10	..	....	750	....
1911	26	..	....	15,214	....
1912	36	..	34,967	31,019	....
1913	51	7	65,689	45,502	....
1914	82	12	96,844	76,977	....
1915*	112	18	120,828	103,959	....
1916	166	25	148,732	167,661	....
1917†	179	34	170,916	266,214	333,390
1918	193	41	183,987	253,562	316,592
1919	208	42	216,086	262,281	328,175
1920	217	43	244,388	283,372	355,798
1921	236	44	265,547	305,247	375,010
1922§‡	247	81	335,000*a*	490,487	572,550
1923§	249	116	400,000*a*	580,392	685,486
1924§	256	124	415,000*a*	655,588*b*	780,789*b*

*Central Ontario system purchased by provincial Government and operated by the Hydro-Electric Power Commission.

†Ontario Power Company taken over by Hydro-Electric Power Commission.

‡Electrical Development Company purchased by Hydro-Electric Power Commission.

a approximate. *b* December load.

Commission Furnishes Electrical Energy at Cost

It is not necessary here to enter into details respecting the means by which the municipalities come into partnership with each other through the agency of the Commission. It is sufficient to state that the municipalities all sign a standard form of contract with the Commission, and agree to corresponding obligations. All the contracts are for a period of thirty years. The fundamental basis of these contracts is that power is supplied to each municipality at *cost.* Inasmuch, however, as the precise meaning of the word "cost," as used in this connection, is frequently misunderstood, it may be of interest to explain this feature. This is especially desirable since fanciful interpretations have been spread abroad—not only in Canada, but in the United States—by those opposed to the Commission's work, with the object of representing that the Commission's operations are not being conducted upon a sound basis.

Briefly, the word "cost" as applied to these contracts embraces all charges involved in the generation, transmission and delivery to the municipality of the agreed-upon amount of power. These charges include the

§The figures for the years 1922, 1923 and 1924 having become available since the report was presented have here been inserted.

municipality's share of the interest and sinking fund for the cost of lands, stations, and equipment necessary to supply the power; also, a proportionate part of the cost of operating, maintaining, renewing and insuring the plant, —and, in fact, all charges which are involved in the business of generating, transmitting, and delivering electrical energy. Administration charges are also included.

Except in the case of rural municipalities, all municipalities in turn pay for and operate their own distribution systems but are under the direct control of the provincial Commission. The Commission must approve all rates for local service and requires that these rates be enforced without discrimination. These rates are determined so as to cover all expenditures incurred locally by the municipality with respect to its distribution service,§ all liabilities of the municipality to the Commission for power supplied, and in addition there is included in the rates paid by the consumer for electrical energy an amount to be set aside as a depreciation fund which, at the termination of the useful life of the plant, will be sufficient for its replacement. In reality, therefore, the municipalities are not only paying for the cost of providing and marketing their power, but in thirty years they virtually receive in revenue an additional amount which, if so applied, would pay for two complete physical equipments. No revenue whatsoever for the Commission's operations is derived from direct taxation. The reserves and surplus available for the twelve municipalities that first entered into contract with the Commission now aggregate five and a half million dollars as against outstanding obligations totalling not quite eleven and a half million dollars.§§ In view of such facts it seems strange that those opposed to public ownership persist in representing that the Commission's operations are not conducted on a conservative and sound basis.

The records of the Commission show that while the power used in the manufacture of war munitions had, by 1918, increased the power requirements considerably above normal, and while just after the armistice there was a considerable drop in the power used, nevertheless the power requirements on the various systems have since taken an upward turn and, since 1920, the rate of increase has become practically normal.§§§

§It should be mentioned that the capital cost is retired by means of a sinking fund, in a period, usually, of twenty years.

§§At the close of the year 1924 the corresponding figures were: Reserves and surplus thirteen million dollars, outstanding obligations twenty-six million dollars.

§§§Since 1921, when this was written, the growth in the electric load of the Hydro-Electric Power Commission of Ontario has been very remarkable, and especially so in view of the rather depressed state of commerce and industry throughout the world. The increased load of electrical energy has come largely through the greater demand from the domestic consumer. The great Queenston-Chippawa hydro-electric plant on the Niagara river near the village of Queenston has an ultimate capacity of 550,000 horsepower, seven units are now installed and the eighth is in process of installation while unit number nine is on order for delivery at the earliest possible date. The output from each unit has been marketed as soon as it has been available. The significance of more recent experiences in the Canadian market is that it is expected there will be no difficulty in marketing in the province of Ontario all the hydro-electrical energy that can be produced from Ontario's equity in the Niagara and the St. Lawrence rivers. See also NOTE on page 20.

Use of Electricity Rapidly Increasing

It is only a few years since electricity was a luxury within the reach of a relatively small proportion of the public, but since its cost has been reduced from about 10 or 12 cents per kilowatt-hour to about 2 or 3 cents per kilowatt-hour electricity has become a common commodity of the people. Upon the part of the general public there is a greatly increased demand for electrical energy. Electrical devices for domestic service, which even a few years ago were a novelty, have now become staple articles of every day use. New applications for electricity in the mechanical and industrial arts are constantly being discovered. Obviously such conditions will substantially increase the per capita consumption.

Per Capita Consumption

The unit figure representing the *average per capita consumption of electrical energy per annum* is one of special importance in connection with the making of estimates respecting the absorptive capacities of markets for electricity.

In Ontario, the per capita consumption at the present time, 1921, is approximately 900 kilowatt-hours per annum. This figure takes into consideration the electrical energy supplied by the Hydro-Electric Power Commission together with that supplied from all other sources, and is based upon the approximate quantity of 2,600,000,000 kilowatt-hours consumed in a territory of about 2,900,000 population.

During the period since the war, the rate of increase in electrical consumption per capita has been less marked than it would have been had general finance and commerce not been passing through a period of special stress and depression. Extreme restrictions imposed upon personal uses of electrical energy during the war period, as well as upon the extension of business not directly germane to the winning of the war, still make their influence felt. In spite, however, of all hindrances or set-backs, it is clear that the use of electrical energy is definitely on the increase and it is believed that the per capita consumption per annum in Ontario will soon reach at least 1,200 kilowatt-hours.

In selecting unit figures for per capita consumption for the purpose of estimating probable markets, full cognizance has been taken of the fact that corresponding figures for certain other territory in the United States and elsewhere have ranged between wide limits. For example, recently one authority gave the annual per capita consumption of electrical energy in certain areas of the United States as follows:

Pacific States	673	kilowatt-hours
Atlantic States	363	" "
New England States	254	" "
United States (average)	334	" "

In this connection it may be asked why these per capita quantities are so much less than the quantities used in estimates presented in this Statement. The explanation lies chiefly in the fact that the large quantities of hydro-electrical power available in Ontario, and the low rates charged, have induced a larger consumption. The reasonableness of the figures employed herein will be more evident if consideration is given to the unit figures deduced in connection with the estimates of consumption of electrical energy in the proposed "Super-Power Zone."

As is known, this so-called super-power zone extends along the Atlantic sea-board from Portsmouth, N.H., to Washington, D.C., and about 150 miles inland, but omits the large power industries in central, western and northern New York and practically all the states of Maine, New Hampshire and Vermont.

The increase in the use of electrical energy in the super-power zone—as presented by the officers of the Super-Power Survey—from 1910 to 1919 inclusive, and the estimated consumption for the years 1925 and 1930, is as follows:

Year	Kilowatt-hours used
1910	4,000,000,000
1915	6,800,000,000
1919	10,301,000,000
1925	22,187,000,000
1930	30,712,000,000

In 1919, a special power census was made and it was estimated that the electrical energy used in the super-power zone in that year was 10,301,000,000 kilowatt-hours. The population of this region in 1920 was about 22,000,000, giving a per capita consumption of 470 kilowatt-hours per annum—a figure which, considering the cheap power available in Ontario, compares not unfavorably with that of 900 kilowatt-hours deduced for this Province.

The estimates for the future requirements of the super-power zone are much more optimistic than the estimates for future consumption employed for the purpose of this Statement. The super-power zone officials' estimate of 30,712,000,000 kilowatt-hours as the energy consumption for 1930 by an estimated population of 25,400,000—a population obtained by using the normal yearly increment of about 1.4 per cent for this portion of the United States—yields a per capita figure of about 1,210 kilowatt-hours. This figure of 1,210 kilowatt-hours may be contrasted with the figure of 900 kilowatt-hours per capita per annum employed herein in estimating consumption for 1931 for the portion of eastern Ontario and, also, for the portion of the United States lying within a 300-mile radius of the suggested St. Lawrence River power development. It should be pointed out that the figure of 900 kilowatt-hours includes nothing for the electrification of railways, whereas the figure of 1,210 kilowatt-hours per capita includes about 200 kilowatt-hours per capita for this purpose, so that the real difference between the

two estimates for the per capita consumption is only 110 kilowatt-hours; the larger estimate is justified for the super-power zone because in it is concentrated the most highly industrialized section of the United States.

Estimated Future Per Capita Consumption in Ontario

The increase of the population of the province of Ontario from 1901 to 1911, was about 15 per cent. For the period from 1911 to 1921, due to war conditions, this rate was decreased. Assuming, however, that the 15 per cent rate is regained during the ten years from 1921 to 1931, the population in the latter year will be about 3,300,000 and in 1941 about 3,800,000. Based upon these populations, and taking a per capita consumption per annum of 1,200 kilowatt-hours in the year 1931, and 1,500 kilowatt-hours in the year 1941, the following figures are deduced:

Year	Estimated total annual consumption	Equivalent maximum loads*	
	kilowatt-hours	kilowatts	horsepower
1931	3,960,000,000	695,000	932,000
1941	5,700,000,000	1,000,000	1,340,000

These estimates signify that the whole of the electrical energy now available, including that to be supplied by the new Queenston-Chippawa development, will largely be absorbed in Ontario alone before 1931. We say "in Ontario alone" because the foregoing estimate takes no account of possible future demand for power for export,§ and although the exported power from the Niagara plants in Ontario has of late been reduced to about 600,000,000 kilowatt-hours per annum, yet at one time it was over 750,000,000 kilowatt-hours or 115,000 horsepower-years. The Commission would point out further that the estimate just made does not include any allowance for the electrification of existent steam railways, nor has any special provision been made for the absorption of large individual blocks of power by specialized new industries such as those now located at Niagara and at Shawinigan.

*Throughout this Statement the figures given for "equivalent maximum loads" are based upon a load factor of 65 per cent. In selecting the load factor which has been applied in connection with the estimates here presented, it may be stated that after carefully determining the load factors appertaining to various representative plants it was concluded that, for the periods of years selected for our estimates, a 65 per cent load factor would be most appropriate for a system which would be built up to utilize the St. Lawrence River power. It may be added that this is about the present load factor of the Niagara system of the Hydro-Electric Power Commission. In the case of central steam plants the load factor usually is much less, and in isolated waterpower plants the installed capacity,—in order to take advantage of seasonal flow, etc.,—is usually greatly in excess of the minimum power available and therefore the annual load factor is also comparatively low.

§See NOTE on page 20.

Power Actually Available Attracts Large Industries

It has been the experience that abundant supplies of cheap power *actually available* undoubtedly attract large basic industries, and the establishment of these, as in the case of Niagara and other large power centres, inevitably results in the establishment also of new by-product industries—which in turn gives rise to increases in population, transportation, and general prosperity such as would not have been created without there first being available large supplies of cheap electrical energy. The Hydro-Electric Power Commission has been handicapped, hitherto, in not having had readily available sufficiently large blocks of electrical energy—apart from those required for municipal and general industrial purposes—after the manner in which electricity has been available in certain other developing centres.

In order further to appreciate the fact that the estimates here presented are conservative, one need but contemplate the great growth which has been manifest in certain places where large quantities of electrical energy have actually been made available. By way of illustration: In 1898 the entire population of Shawinigan lived in one house. Shawinigan was then "in the woods." Its population now exceeds 14,000. In 1902, 10,000 horsepower was installed at Shawinigan while at the present time the total capacity is about 190,000 horsepower.

A recently published summary* of the power situation in this locality gives the following figures:

	Horsepower
Electrical equipment now installed	326,200
Hydraulic power supplied	50,000
Power used by Laurentide Co	37,500
Future provision at Laurentide	20,000
Future additional development at Shawinigan	60,000
Future development at Gres Falls	150,000
Total	643,700

Of this total, 413,700 horsepower is now installed, or being installed as hydraulic or electric power, leaving 230,000 horsepower for future development.

About 1901, the Northern Aluminum Company's plant was using 5,000 horsepower. To-day it uses over 50,000 horsepower, employs over 800 men and produces daily 60,000 pounds of aluminum. The Canadian Aloxite Company commenced operations about 5 years ago and in the near future expects to utilize 20,000 horsepower.

Local industries including in addition to those just mentioned, others like the Canadian Electric Products Company, the Canadian Electrode Company, the Prest-O-Lite Company, and the Shawinigan Cotton Company, utilize, it is said, about 55 per cent of the total power sold by the Shawinigan

*"Industrial Canada," May, 1921.

Company. Of the remainder, it has been stated that 25 per cent of the power goes to the Montreal district, 10 per cent to the asbestos region, and 10 per cent to Three Rivers and Quebec.

Possible Markets for St. Lawrence Power

Having now directed special attention to the subject of per capita rate of consumption of electrical energy per annum, and to the rapid growth in consumption that has taken place where large developments have been made, it will be profitable to survey the principal markets, which would probably first be available for the absorption of the electrical energy proposed to be developed from the water power of the St. Lawrence river. These markets, broadly speaking, are the easterly portion of the province of Ontario, and the north-easterly portion of the United States.

Markets in Eastern Ontario

With regard to the easterly portion of the province of Ontario, it may be stated that the water powers scattered over this territory—which are relatively small in size—have practically all been placed in service.

There is in Ontario, within a radius of 200 miles of the power sites on the Ontario portion of the St. Lawrence river, a population of approximately 550,000. Giving due weight to the rural character of the larger portion of the present population, and taking into consideration the fact that large blocks of power once available will attract industries and population, it is reasonable to assume that, if power be available by 1926, the population in the succeeding five years would increase to about 580,000, and in the next ten years would probably rise to about 665,000.

Again, taking cognizance of the character of the population, and having observed what has elsewhere occurred, it is possible that in five years from the commencement of the supply of power the consumption per capita per annum may not reach more than about 900 kilowatt-hours. On this basis, by 1931, there would be a power consumption of about 520,000,000 kilowatt-hours equivalent to a maximum load of about 90,000 kilowatts, or 121,000 horsepower.

By 1941, the per capita consumption would probably rise to 1,200 kilowatt-hours. If such growth took place, it would result in a total consumption of 800,000,000 kilowatt-hours, equivalent to a maximum load of about 140,000 kilowatts, or 190,000 horsepower. This estimate,—as was the case in that previously given for the territory now served by the Hydro-Electric Power Commission,—neglects the possible demands for the electrification of steam roads and the power required for specially large new industries attracted by the cheap power. The estimate also neglects the possible demands for power for exportation.§

§See NOTES on pages 17 and 20.

Markets in North-easterly United States

Consider, next, the possible market in the north-easterly portion of the United States.

Within a radius of 300 miles from the upper portion of the St. Lawrence river—from near Cornwall, Ontario—there is in the United States, a population of about 23,000,000, which, on the pre-war rate of increase in population of about 1.4 per cent per annum, will, by 1931, probably be 26,420,000, and, by 1941, 30,400,000.

Assuming that by 1931, the per capita consumption of electrical energy is no more than 900 kilowatt-hours, there would result in this territory, a total consumption of 23,780,000,000 kilowatt-hours, equivalent to a maximum load of 4,200,000 kilowatts, or 5,600,000 horsepower. It may reasonably be assumed that by 1941, with large quantities of hydro-electric power available, supplementing the supply from other sources, an average per capita consumption of about 1,200 kilowatt-hours would be reached. This is equivalent to a consumption of 36,480,000,000 kilowatt-hours, and to a maximum load of about 6,400,000 kilowatts or 8,600,000 horsepower.

It may here be remarked that, if power from the St. Lawrence river be transmitted to some of the large centres of population, such as New York city, Philadelphia and Boston, very considerable loads could, almost from the commencement, be built up in such centres. The existence of such highly favourable terminal conditions would practically justify the building of the transmission lines for these loads alone, and then other loads, for which it would not otherwise pay to build the lines, could be picked up en route.§

The Lower St. Lawrence River

The Commission's engineers refer to the large water powers which are on the St. Lawrence river in the province of Quebec. The Commission has understood that officials of that province, like those of the province of Ontario, have been requested to submit data to your tribunal which will comprise reference to the physical, economic and other aspects of these water powers and consequently the Commission has only dealt with the upper or international power stretch of the St. Lawrence. It may be found best to develop power first in this international portion of the river in order that the United States may, as soon as possible, have her equity in this international power available for her own needy markets.

Summary of Prospective Markets

Summarizing now the requirements as previously estimated for eastern Ontario within a radius of 200 miles, and for that portion of the United States

§Probable demands for power in Ontario now render it unnecessary to consider this field. Consult NOTE on page 20.

lying within a radius of 300 miles from the upper St. Lawrence, the following are the approximate results:

Year	Estimated total annual consumption	Equivalent maximum loads	
	kilowatt-hours	kilowatts	horsepower
1931	24,300,000,000	4,290,000	5,720,000
1941	37,280,000,000	6,540,000	8,790,000

From the foregoing considerations, it is obvious that in the area to which it would be possible, economically, to transmit St. Lawrence power (excluding possible markets in Quebec), there must automatically arise a greatly increased demand for new electrical energy which will be required to supply such markets as will be developed by an increasing per capita consumption of a population which is itself increased by normal growth. This increased demand—according to the figures we have submitted—will, by 1931, necessitate an additional maximum capacity over and above that at present available of nearly 3,000,000 horsepower, and by 1941, of a further amount of over 3,000,000 horsepower.

Map of Transmission Systems

In the Appendix of maps and plans accompanying the Engineering Report will be found a map showing "Present Transmission Systems in Ontario and Quebec, Canada, and North-Eastern United States, also Proposed New Trunk Lines," from which it is evident that both in Canada and in the United States there are a number of large transmission systems within the area which may readily be supplied by transmission lines from the water powers of the St. Lawrence.

It seems clear, that if one or more large trunk transmission lines were carried through the territory in which these networks are, power would begin to flow from these trunk lines to feed the markets represented by the various distributing networks, or subsidiary transmission systems. It also seems clear that these existent distribution systems will constitute the centres from which the network will be extended until finally it spreads out and embraces within its meshes the whole territory within transmission distance of the St. Lawrence river. Indeed one may go further and state that the time is probably coming when the territory from Quebec city on the east to Chicago on the west and from Washington, D.C., on the south to the mining areas of Northern Ontario will be linked up, by interlocking transmission lines, to the two great sources of primary power—Niagara and the St. Lawrence.

Present Figures of Per Capita Consumption will be Substantially Increased

The figures herein given to represent the future consumption per capita per annum of electrical energy do not include special allowance for steam power being replaced on a large scale by hydro-electric power; for the elec-

trification of steam railroads; nor, in the case of Ontario, for the requirements of the foreign or export market. The demands for such services, will, it is true, greatly enlarge the market for electrical energy, but the amounts thus required cannot be determined with the definiteness of the per capita figures previously submitted, based as they are upon well-authenticated data. It is deemed best, therefore, to keep these known per capita figures distinct, because to them may be added such extra demands as may, later, more accurately be estimated for other large specialized markets such as have just been mentioned. Before passing to the second main portion of our Statement, it will be desirable briefly to survey these special markets in order that their individual significance may better be appreciated.

Special Markets

Prospective Demand for Electric Power to Replace Steam Power

First, then, with respect to the markets arising from the replacement of steam by hydro-electrical power. This is a field which does not lend itself to definite appraisal, but one which will doubtless provide an outlet for great quantities of hydro-electrical energy.

There is little opportunity in easterly Ontario to substitute electrical energy for steam power, because in this territory there is relatively little steam power used.

In the north-eastern United States, however, the situation is very different, because within transmission distance of the St. Lawrence river, there are numerous steam plants, many of which are large, modern, and highly efficient. This fact suggests the possibility that the process of supplanting such steam power may be somewhat slower than would be the case if all the steam plants were small and comparatively inefficient. The large amount of capital invested in such plants precludes any possibility of their being "scrapped." Always assuming that the delivered cost of St. Lawrence River power will be such as to enable it successfully to compete with steam-generated power, an evolutionary process must ensue, which in its early stages, will involve the taking of St. Lawrence River power by steam-generating public service corporations in order to meet *increasing* demands on their *existing* central stations. This process will gradually develop until the original steam stations become "peak-load carriers" and "stand-bys" only, because the whole of their base loads will gradually have been transferred, to be carried by power derived from the St. Lawrence river, or from other available hydraulic sources.

Based upon the determined rate of growth in the proposed super-power zone, it has been estimated that, by 1930, the consumption of electricity will amount to about 30,700,000,000 kilowatt-hours, which with a 40 per cent load factor is equivalent to a maximum demand of about 8,800,000 kilowatts or 11,800,000 horsepower. It will, therefore, be perceived that if

only so low a proportion as five per cent of this maximum power demand could be diverted or connected up within the five first years of the development of the St. Lawrence River power, it would amount to about 600,000 horsepower. The super-power zone, as has already been stated, excludes the big power industries in central, western and northern New York, and practically all of the states of Maine, New Hampshire and Vermont. Although a considerable portion of the New York State load will be supplied from Niagara Falls, and although the other states mentioned do not contain such large industrial centres, nevertheless, an appreciable load will, no doubt, be connected up along the route of the proposed transmission lines of the super-power zone.

Further research will give warrant for the selection of a figure which will more intelligently represent the amounts of steam power that may be replaced by electrical power, but, meantime, it may be recognized from the figures just submitted that there is the possibility of a large market for electrical power to replace steam power in the territory under review.

Respecting Electrification of Steam Railways

Those who have followed the great advance which in recent years has been made in the electrification of steam railroads, have recognized that this sphere of activity is sure to create a largely increased demand for electrical energy.

The possibility of effecting large savings in the amount of coal required for railway purposes in Canada and the United States, is a subject which has attracted the attention of both nations. No other single field of industrial or commercial operations offers such possibilities for effecting savings as the railroads.

No one would suggest that the whole of the railways of eastern Canada will be electrified at the same time. It is reasonable to suppose, however, that within five years after the time when the St. Lawrence River power development might be ready—say by 1931—a section of 125 miles of the line of either the Canadian Pacific Railway or the Canadian National Railway might be electrified. This would create a power demand of from 10,000 horsepower to 15,000 horsepower. In the succeeding 10 years, that is by 1941, it is not unreasonable to expect a power demand from the same source of from 30,000 horsepower to 40,000 horsepower. With regard to the northeastern United States, it may be observed that, given an ample supply of cheap electrical energy, a railway load of from 25,000 horsepower to 30,000 horsepower might be created by 1931, and possibly by 1941, a load of from 80,000 horsepower to 100,000 horsepower. These figures are merely suggestive, and are offered in order to indicate how, even when viewed conservatively, the possible demand for energy for the electrification of steam roads may reach quantities which would constitute a substantial contribution to the load for the water powers of the St. Lawrence river.

Possible Demand for Electrical Energy for Navigation, etc.

Other possible new demands for electrical energy might be pointed out; for example, there will be a considerable demand for electrical energy to meet the needs of navigation. Power will be required for operating navigation structures, for lighting portions of the route, and for the service of numerous small communities which doubtless will spring up in connection with the proposed development. All such demands will assist in swelling the electrical load. We shall not attempt to enlarge upon this phase of the problem.

Exportation of Electricity

In the course of this Statement we have several times drawn specific attention to the large potential markets in the United States for the absorption of electrical energy. The relationship which such markets bear to Canada's share of the St. Lawrence River power is that, for a time at least, it is probable that a portion of Canada's share of the available power may be used to supply the United States market to the mutual advantage of both countries.

As is known, the United States Federal Government has provided legislation governing the *importation* and the Federal Government of Canada has provided legislation governing the *exportation* of electrical energy to the United States. It has been contended that no Canadian electrical energy should be exported, but in view of the existent legislation and the action which has been taken thereunder, it is evident that the federal governments of both countries have contemplated the possible continued exportation of electricity from this Dominion to the United States, or *vice versa.*§

In referring to this subject we do so on the assumption, *first*, that the exportation of electrical energy in large quantities shall only be permitted under strict governmental control as under the Canadian Electricity and Fluid Exportation Act; *second*, that the operations be conducted upon a sound economic basis; and *third*, that full, proper and workable provision be made for the progressive reclamation of all exported power as and when the need arises for its use in Canada.

In the case of Niagara power, communities and large private interests scattered over a wide territory in the United States soon became aware of the great advantage it would be to them to have large quantities of Canada's electrical energy imported for their use. Many who some day may be

§For a discussion of the subject, "The Exportation of Electricity," consult article under this title by Arthur V. White in *The University Magazine* (Montreal) for October, 1910, pages 460-467; and for further survey of various aspects of this subject consult articles by the same author as cited in Chapter VI dealing with the "Exportation of Electricity" appearing on pages 141-149 of *Report on Water Powers of British Columbia*, published by the Commission of Conservation of Canada, Ottawa, 1919; consult also, the following *Annual Reports of the Commission of Conservation—Sixth* (1915), pp. 144-148; *Seventh* (1919) pp. 179-181; *Eighth* (1917) pp. 230-235; *Ninth* (1918) pp. 75-91; and respecting the "Restricted Possibilities of Electric Heating," consult the *Tenth Annual Report* (1919) p. 236; consult also note §§§ on page 5, *supra*.

served by St. Lawrence River power, have not yet awakened to a realization of what this power means to them, and consequently have not expressed their views in a manner similar to those who have sought imported Niagara power. Once the advantages and possibilities of St. Lawrence River power are widely sensed, arguments will be heard in the north-easterly States similar to those voiced respecting imported Niagara power. It has already been emphasized that there is an increasing demand for more hydro-electrical energy in the eastern portion of the United States. Although the United States possesses a large amount of water power, nevertheless, practically 70 per cent of it lies within eleven of the western states. In the New England states over 75 per cent of the potential water powers have already been developed and for this area future increments in developed water power will be obtained largely by the more efficient utilization—chiefly through storage—of the streams already developed—or by drawing upon the potentiality of the St. Lawrence river.

For several years New York state, as is well known, has been short of hydro-electrical power, and the demand for more has been great and insistent. The *Opinion*, delivered a few years ago by the Public Service Commission of the state of New York, records that:

> "There is a large shortage of electric power in western New York, with a strong demand for greater supply which is not being met by existing companies. . . . . We are using all the power made on the New York side, and all that has been brought from Canada, and *the demand for more power in western New York is insistent and being urged with great force.*"

It was also stated that Niagara Falls power produced in the United States is so far from supplying the needs of portions of the state of New York, that if the importation of power from Canada were prohibited it "would plainly amount to a great public calamity."

Desire for Canada's Power in Boundary Waters

To meet such demands, the water power derivable from Canada's equity in international waters is coveted. To remove any doubt regarding this matter, we shall quote a few authoritative statements. The District Engineer in charge of Niagara waters for the United States War Department reporting upon the subject of Niagara power to the Chief of Engineers, U.S. Army, has stated that:

> "There is no question but that Niagara power will soon be utilized to the fullest extent allowed by governmental restrictions. *If advantage of the power generated in Canada cannot be had on the American side, manufacturers will be attracted to Canada* by this cheap power, and the industries of this country will suffer accordingly. It, therefore, seems advisable to permit immediately the importation of Niagara power to the fullest extent permissible under the law, and, other things being equal, to grant permission for its importation to the company or companies which will make the earliest use of such power."

Speaking before the Committee on Foreign Affairs, a former Secretary of War for the United States said:

> "The investigation which has been made by the engineers indicates that Canada, if we do not take it, will use the entire amount that the treaty permits in a very brief time, so that whatever effect any restrictions on importations would have, would not protect the Falls for more than a very brief period, and *it would result in giving to Canada, very possibly, a large number of industries which otherwise would be established on this side of the Falls.*"

The representative of the United States Congress from the state of New York, when speaking on behalf of a Bill relating to Niagara matters, stated:

> "Every restriction on the importation of Canadian power should be at once removed. Electrical power is raw material and should be free."

In its report on one of the Niagara bills, the Sub-Committee on Niagara Falls power of the United States Congress records that it had been urged for its attention:

> "That the Canadian companies were rapidly increasing their sales and would very soon take the full amount of water they were entitled to and the United States ought to get what power it was able to *now.*"

and they add:

> "If the advancement in the development of power on the Canadian side increased for another year or so—and it is not apparent to the committee that it will not—then the *committee concluded that it was proper to take as large an amount as it could get for consumption in the villages, cities, factories and homes along our border.*"

Even these few statements, from amongst many, demonstrate that there has been a very great demand for electrical energy.§

Canada already is an exporter of electricity, exporting this energy from New Brunswick to the state of Maine, from Quebec to New York, from Ontario to New York and Minnesota, and from British Columbia to the state of Washington. At times the total quantity exported has aggregated over 180,000 horsepower-years. Last year the quantity exported from the Niagara Falls plants in Canada aggregated about 110,000 horsepower-years. There is little doubt that if cheap electrical energy be developed from the St. Lawrence River water powers there will arise a strong demand for its importation into the north-eastern portion of the United States to which reference has previously been made.§§

This Commission does not suggest that Canada should carelessly part with, nor even compromise, her heritage in the water powers along boundary waters, but there are doubtless considerations which may make it of mutual advantage to the United States and to Canada to co-operate in connection with the utilization of electrical energy. At the present time our telegraph lines, railways and steamships practically disregard the international bound-

§See notes on pages 5 and 17. §§See NOTE on page 20.

ary and seek such freedom of intercourse as will facilitate international intercommunication and the general welfare of commerce. Correspondingly, under proper safeguards, there appears to be no reason why interchange of electrical energy should not be effected along satisfactory lines.§

Thus far in the course of this Statement it has been observed that there have been expanding markets for the consumption of electrical energy both in Canada and in the United States and that such markets promise still greater expansions. Attention has been directed to the increase in *the rate of increase* of the per capita consumption per annum and also to the large demand which must automatically arise due to the natural increase of population. It was further pointed out that there will doubtless be a large demand for electrical energy for large specialized basic industries, for the replace-

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NOTE

§When this Report of 1921 by the Hydro-Electric Power Commission of Ontario respecting the proposed development of the St. Lawrence river was in course of preparation, it was appreciated that the after effects of the Great War upon the growth in demand for electrical energy could not satisfactorily be determined. There were also other factors affecting the possible demand which were difficult to evaluate with assurance. It was, for example, thought that the areas now served from Niagara would continue to be so served for some years, although there would be interlocking provisions by which there could, if found desirable, be interchange of power between the plants on the Niagara river and the developments proposed for the St. Lawrence and Ottawa rivers. In view of such circumstances, the Commission felt constrained to exercise extra caution to ensure that its estimates should be amply conservative.

Since the Report was presented, a substantial body of additional information resulting from researches conducted by special public organizations both in Canada and in the United States has become available. The output of the Commission's great Queenston-Chippawa generating plant has been marketed as rapidly as each unit could successively be installed, a fact which shows that throughout southwesterly Ontario as now served from Niagara there will soon be a demand for more power than can be developed by the full installation at Queenston. In connection with the utilization of the power of the St. Lawrence river, this populous and highly-developed territory was not in the former estimates given the prominence that more recent facts have indicated it must now have. In other words, the radius of the territory in Ontario which must be served by St. Lawrence River power has been demonstrated to be much greater than that comprised in the earlier estimates and the transmission distance of but 200 miles assumed for the region to be supplied from the St. Lawrence has now to be substantially increased. Instead of serving, as was estimated, an area in Canada with but half a million of population, there will be an area with nearly two and a half millions of population to be taken into consideration.

In view of the factors just mentioned, the Commission is justified in now submitting a revised estimate supported by later definite data. This later estimate is, however, still amply conservative.

The Commission, in its Report as submitted in 1921, assumed that an increase in *per capita consumption per annum* of 33 per cent would take place in the ten-year period from 1921 to 1931. Recent records issued by the Bureau of Statistics of the Dominion of Canada indicate that this percentage increase of *per capita consumption per annum* in the province of Ontario was attained in about two years. This remarkable growth has resulted chiefly from the greatly-increased appreciation of the convenience and economy attaching to the use of electricity and from reduction in prices of energy made possible by the expansion in use.

ment of steam power and for the electrification of steam railroads. In fact, it has been demonstrated that markets exist which give promise of absorbing practically all of the hydro-electrical energy which the St. Lawrence River water powers could develop.

Obviously, the foregoing considerations involving the marketing of electrical energy are, in turn, dependent upon the assumption that the electrical energy may profitably be sold at prices which will induce its purchase and use in large quantities. The problem therefore demands that it be ascertained whether the hydraulic and other physical factors governing in the proposed development of the St. Lawrence water powers can be made to generate the electrical energy at a cost sufficiently low to guarantee an attractively low rate to the consumer.

Studies based upon the rates of increase in recent years presented by the various public organizations already referred to and based also upon the Commission's careful examination of its own and other loads show that, in recent years, in the United States, consumption has doubled in about six years, while in Canada as a whole the rate of increase is even higher. The significance of the rapid increase in the demand for power in Ontario may better be appreciated from the statement that the *annual* rate of increase of the Commission's own loads will by 1931 reach 100,000 horsepower.

At present, the judgment of the Commission is that it will be necessary to provide new sources of electrical power amounting to more than 400,000 horsepower by 1931, which would be increased to over 1,100,000 horsepower by 1936. The Commission, as is known, has earnestly sought authority to proceed with the development of Ontario's portion of power in the international section of the St. Lawrence. Had this authority been granted even in 1923, and the Morrisburg site been developed to deliver the initial power by 1927 the whole of this power would have been in use by 1930; and had the construction of the Long Sault development been planned to commence when the development at the Morrisburg site started to deliver power, it would have been possible to deliver power from the Long Sault plant by about 1930 or 1931 and its output would probably have been completely utilized in the province of Ontario by 1934.

Due to the fact that the authority sought was not granted, the Commission is under the necessity of constructing large steam-electric plants and this the Commission is proceeding to do. Viewing the future power markets in the light of present information, it may be stated that if authority were immediately granted to develop the international portion of the St. Lawrence, the Morrisburg plant would not be ready before 1929, and by that time it is probable that there will be a load to be carried by steam-electric plants aggregating some 250,000 horsepower,—necessitating the consumption annually of over half-a-million tons of coal Under these circumstances—and assuming construction work on the Long Sault development to commence as soon as possible after the Morrisburg development has reached a stage which makes it practicable—the Long Sault development could commence to deliver power by about 1932 and by 1935 or 1936 the whole of Ontario's share of the St. Lawrence River power would probably be absorbed by the Ontario markets alone.

In conclusion, it may be commented that if wholly unforeseen eventualities should arise to alter some of the factors entering into the conservative estimates just presented, there might result some surplus power from the St. Lawrence, but the period over which it would not be required in the province of Ontario would, doubtless, be transient and brief. The contingency that the Ontario markets will not absorb all of Ontario's electrical energy that can be made available within the periods stated may be regarded as remote.

Physical Aspects of the Proposed Development of the St. Lawrence River

Discussion of the physical aspects of the proposed development of the St. Lawrence river may be introduced by drawing attention to the large amount of special engineering investigation and other work which, especially during the last ten years, has been performed in connection with the St. Lawrence river.

Power Shortage in Eastern Ontario

The Hydro-Electric Power Commission, as previously noted, has given special attention to market and other conditions associated with the development of the power resources of the St. Lawrence river.

The Commission had recognized that the industrial growth of the Ontario municipalities along the north shore of the St. Lawrence river was being seriously curtailed through failure to obtain an adequate supply of hydro-electrical energy. In 1906, the Commission initiated special investigation with a view to securing adequate supplies of power for these municipalities. The application which the New York and Ontario Power Company had before the International Joint Commission for the development of its power site on the Little river near the village of Waddington, brought to the attention of the Joint Commission the specific effort which in 1911 the Hydro-Electric Power Commission made to secure power from this company for distribution to the municipalities between Kingston and Cornwall and as far north as Perth and Smiths Falls. The vital importance of a comprehensive development of the St. Lawrence river had not been overlooked, even though the Hydro-Electric Power Commission sought to obtain power for certain municipalities before the desirability of making available larger quantities of St. Lawrence River power had been as widely recognized as it is to-day.

Commission's Engineers Delegated to Study St. Lawrence River

When active operations in connection with the construction of the new Welland ship canal were commenced, the Commission foresaw that before many years it would become necessary to take action with respect to the St. Lawrence portion of the Great Lakes' route to the sea. The Dominion Minister of Railways and Canals, the late Hon. Frank Cochrane, suggested that the Hydro-Electric Power Commission should commence a series of preliminary power development studies on the International section of the St. Lawrence. Accordingly, in 1913, special investigations were commenced and have since been carried on more or less continuously.

The Commission, early in 1918, decided to delegate engineers to undertake an intensive study of the power situation on the upper St. Lawrence river. Upon this engineering staff were men who had previously devoted special and extensive study to various conditions prevailing along the St. Lawrence river; also other engineers possessed of wide practical experience who are expert in problems relating to the development, on a large scale, of hydro-electric power.

This study has involved the making of accurate contour surveys on both of the shores of the St. Lawrence river between Prescott and Cornwall; foundation explorations including extensive boring in the vicinity of possible sites for dams; extensive sounding operations in the river itself; the gathering of special hydrometric data, including the making of a comprehensive and continuous study of the variations of water level, and, in fact, of the general hydrological conditions of the St. Lawrence river.

The manner in which these data have been obtained and the various ways in which they have been adapted to serve as a basis for estimates and recommendations, are items which are described in detail in the Engineering Report accompanying this Statement. It is desirable however, to refer here to the scope and character of the special efforts which have been made by the Commission's engineers in order that your Commission may feel warranted in according to their conclusions the weight to which the Hydro-Electric Power Commission believes they are entitled.

Co-operation in Securing Data

The Commission wishes to acknowledge in the fullest manner the valuable data which have been obtained by other organizations both governmental and private. The Canadian Departments of Railways and Canals, of Public Works, and of the Interior, also the United States Lake Survey, have supplied valuable hydrometric data. The records of the Dominion Department of Railways and Canals are of exceptional service, covering, as they do, daily lock-gauge readings for the period from 1860 to date. The former Deep Waterways Commission, the Department of the Naval Service of Canada and the International Boundary Commission have also gathered valuable topographical, hydrological and other data. The New York and Ontario Power Company, the St. Lawrence River Power Company and other private interests likewise have obtained—though to a lesser extent—corresponding data. There has been a generous interchange of information between these organizations and the Commission's engineers, and such information has been put to the fullest possible use. There has, in fact, been an assemblage of all known data. The uses to which these data have been applied are set forth in the Engineering Report and consequently need not be discussed here. The Commission wishes, however, to point out that the detailed field data appertaining to the larger portion of the upper St. Lawrence territory, have resulted from the efforts of the engineers who were placed in the field by the

Hydro-Electric Power Commission. This fact is cited because the Commission wishes the International Joint Commission to know that the studies and conclusions reached by the Hydro-Electric Power Commission's engineers have been based upon an earnest attempt to obtain first-hand knowledge of all essential factors—so far as these could be obtained in the time available—in order that the conclusions should rest upon a solid foundation. The Hydro-Electric Power Commission has encouraged its engineers to spare no reasonable effort in connection with this investigation.

On the Canadian side of the river, the Commission's surveys are carried between Prescott and Lock 19 of the Cornwall canal. On the United States side they extend from the State Hospital, opposite Chimney island to the intake of the Massena power canal. Contours on the ground, also essential topographical features and cultures were determined. A complete survey was made of the villages of Farran Point, Aultsville, Morrisburg, Iroquois, Waddington, and that part of Cardinal lying below elevation 250. Soundings of the river were secured at various governing points for the purpose of supplementing or verifying information already available. Special soundings were made, as well as rock drilling, in order to develop as fully as possible the subaqueous contours of the river between the lower end of Ogden island and the head of Doran island.

In the report of the Commission's engineers will be found an extensive discussion of the physical factors germane to any proposed development of the St. Lawrence. We shall here briefly refer to some of these factors because of their general interest and significance in connection with this Statement.

General Hydrological Conditions

An examination of the map of the world discloses the fact that the Great Lakes' system of North America, including the St. Lawrence river, constitutes an outstanding and unique geographical feature. Many persons have drawn attention to phenomenal characteristics appertaining to these waters. It is not the intention here to review these at length but simply to direct attention to a few facts which have been brought into special prominence as a result of recent engineering investigation, in order that the advantages to be derived from some of these special characteristics may be duly appreciated in connection with the development of the water powers of the St. Lawrence. A fuller setting forth of these and other physical factors will be found in the Engineering Report.

The watershed of the St. Lawrence river above Quebec is about 415,000 square miles and its length to the head of lake Superior is about 1,600 miles, but although it is one of the larger rivers of the world, the St. Lawrence, viewed from some standpoints—such as watershed area and length—is by no means in the front rank.

Remarkably Uniform Flow

Its outstanding physical characteristic from a water-power standpoint is the dependability and uniformity of its flow. In this respect it undoubtedly ranks as the most remarkable of the larger rivers of the world.

This marked uniformity of flow results from the balancing of the water supply to lake Ontario which, in turn, reflects the natural regulation of the storage capacities of lakes Erie, Huron, Michigan and Superior.

The outflow from lake Ontario is controlled by the ridge of hard rock which crosses the bed of the river at the head of the Galop rapid, about five miles below Ogdensburg and Prescott, and hence the flow of the St. Lawrence river is, practically, dependent upon the elevation of the water above the crest of this ridge.

From the foot of the lake to Prescott, owing to the great depth and cross-section of the river channel, the velocity of flow is very low and the surface slope—being less than ¼ inch per mile—is so slight as to be almost negligible. This stretch of 60 miles of the river may be regarded as simply an arm or extension eastward of the lake.

The average discharge of the St. Lawrence during the sixty-year period of observation was about 247,000 cubic feet per second.

The remarkable uniformity of discharge of the St. Lawrence river may be contrasted with the fluctuations of other rivers. Consider, for example, the Columbia river of British Columbia and the Western States, with a drainage area of 259,000 square mies, and a total length of 1,150 miles. Its average discharge over a period of nearly 40 years is about 210,000 second feet. The Columbia therefore is comparable in magnitude with the St. Lawrence. It has been officially stated that the Columbia river and its tributaries afford at least one-third of the available water power in the entire United States. The fluctuations in the discharge of the Columbia, although much less than for many other large rivers, are considerable; the maximum recorded discharge is 1,160,000 second feet or over three and one-half times the maximum discharge for the St. Lawrence; the miminum recorded is 41,900 second feet or less than one-fourth the minimum recorded for the St. Lawrence. The ratio of maximum to minimum discharges on the Columbia is 27 to 1, as compared with less than 2 to 1 on the St. Lawrence. These variations in discharge are usually accompanied by corresponding variations in stage. On the Columbia river, for example, in the vicinity of possible power sites, the fluctuations in level between high and low water over long stretches of the river exceed thirty feet. On the Fraser river, in British Columbia, at one place the variation in level between high water and low water is about 90 feet.

This fact of the known dependable and uniform character of the discharge of the St. Lawrence river is emphasized because, apart from its favour-

able influence on the amount of power available, it is one of paramount importance in facilitating its development for power and for navigation. This steadiness and dependableness of the river, including the narrow range in fluctuation in levels, practically remove what has usually been found to be the most serious difficulty encountered in the carrying out of projects such as the International Joint Commission has under consideration. On rivers subject to great variation in discharge, sudden freshets, causing excessive rises and flooding of entire works, have not infrequently resulted in great loss and in injury to plants both while under construction and when completed. Again, with conditions of flow so well known, provision may be made to meet requirements with much greater precision than would be the case with streams subject to greater fluctuations.

Contrary to popular surmise the magnitude of the flow of the St. Lawrence river, by itself considered, constitutes no special menace to the carrying out of the engineering works proposed. On the contrary, there are many rivers in which power works have actually been constructed under circumstances much more trying from an engineering standpoint than could arise from a river with so uniform a regimen as the St. Lawrence.

St. Lawrence River Water Power Reaches

Viewed from the standpoint of the development of power the St. Lawrence river may be considered as having its total fall of about 225 feet, which takes place from Prescott to Montreal,—a distance of about 120 miles—broken up into three separate sections or reaches.

(1) From the head of the Galops rapid to the foot of the Long Sault.

(2) From the head of the Coteau rapid to the foot of the Cascades rapid.

(3) From the head of the Lachine rapid to Montreal harbour.

These reaches are separated by the river expansions of lake St. Francis and lake St. Louis and for convenience may be referred to as *power reaches.*

In the upper power reach extending from Prescott to Cornwall, a distance of nearly 50 miles, there is a total fall of a little over 90 feet. About half of this takes place in the Long Sault and the balance in the Galops rapid, rapide Plat and Farran Point rapid and in the swiftly flowing intervening stretches of the river. Between 80 and 85 feet of this fall can be utilized for power development.

Between lake St. Francis and lake St. Louis, there are, in a distance of about 15 miles, three rapids—the Coteau, Cedars and Cascades, with a total fall of about 82 feet of which about 75 feet is available for power.

Between lake St. Louis and Montreal harbour the total fall, including the Lachine rapid, is about 45 feet; and of this from 30 to 35 feet, according to the stage of the river, can be developed for power.

The two expansions of lake St. Louis and lake St. Francis may be left out of consideration so far as the construction of works for the development of power is concerned. The country surrounding those lakes is so low as to make it impracticable to raise the elevation of their surfaces above the maximum stages reached under natural conditions.

The report of the Government engineers shows that in the two lower power reaches just referred to the local conditions are unusually favourable for the improvement of navigation by the use of locks and side canals. This is a very important feature from the standpoint of the development of the river as a whole, because the work connected with any proposed development of power in these lower reaches of the river may be regarded as a distinct proposition to be dealt with either simultaneously with navigation improvements or at a later date.

The total undeveloped power which can be developed in the St. Lawrence in the three power reaches referred to amounts in round numbers to about 4,000,000 horsepower of 24-hour power, of which about one-sixth may be obtained in the lowest reach and the balance in about equal amounts from each of the two upper reaches. The power already developed on the St. Lawrence totals about 300,000 horsepower, of which over 200,000 horsepower is on the Canadian side of the boundary, and of which the greater part has been installed within the last six or eight years. New equipment is now being planned which will increase the capacity of the Canadian plants by 60,000 horsepower.

International Power Reach

Now, the upper power reach of the St. Lawrence, whether viewed from the standpoint of the development of power or of navigation or of both, demands different consideration from the lower power reaches. In this upper reach it is much simpler to provide for the carrying out of the requirements of improved navigation than to provide for those of power development, because the period of navigation is confined to the season of open water and consequently the serious difficulties involved in dealing with ice are largely avoided. This upper reach, however, differs from the two lower reaches in being particularly well adapted to an improvement for navigation by canalization of the river, and less suitable for the construction of side canals and locks. Viewed from the standpoint of navigation alone, canalization has been conceded the best method by all who have investigated this phase of the problem. The Government engineers have recommended canalization with the incidental development of power. The Hydro-Electric Power Commission in conducting its investigations, has sought the most practical and economical methods for developing the maximum amount of power derivable from this upper reach of the river, while at the same time keeping to the forefront the paramount importance of navigation. The Commission's engineers, therefore, have made such selections in the situations

and designs of dams and other power structures as shall best accord with the requirements of improved navigation, and, at the same time protect against the serious difficulties arising from ice conditions.

During the period of construction, provision would be made for maintaining the present "fourteen-foot" navigation between Prescott and Montreal by a system of side canals and locks where open river navigation is not feasible.

Schemes Suggested by Hydro-Electric Power Commission's Engineers

Attention may now be directed to the engineering schemes for which the Hydro-Electric Power Commission desires the consideration of the International Joint Commisson.

These specific schemes are confined to the upper power reach. This is the stretch of the river which borders the province of Ontario and the state of New York and which constitutes the international portion of the St. Lawrence. It will be unnecessary here to enter into any detailed description of the suggestions made by the Commission's engineers in so far as they relate to the problem of navigation, chiefly because these suggestions are set forth in detail in the Engineering Report and may best be followed by using the maps which accompany the engineering descriptions. Attention, therefore, will be directed specifically to the recommendations made respecting the development of power.

Change Required in International Boundary

The studies made and conclusions submitted by the Commission's engineers respecting the improvement of the St. Lawrence river for navigation and for power are based primarily upon the physical and economic factors involved, and consequently the engineers have considered the placing of proposed power structures upon what, viewed from an engineering standpoint, appear to be the best sites irrespective of the present position of the international boundary.

Although development of the St. Lawrence river might be so made as to place the power houses of each country entirely within each country's present boundary, nevertheless, in the case of the St. Lawrence it would prove of substantial financial and other benefit to both countries concerned if the limitations imposed by the present position of the international boundary could be removed, and the power-house structures placed in the positions which would take advantage of favourable physical conditions. When the final plans are approved and before any construction is commenced it will be necessary very slightly to alter and re-establish the international boundary line in such positions as would place each country's power installation, respectively, within its own domain.§

§ Since this report was submitted, further studies of possible power-house situations have been made and these studies indicate that it is feasible to locate the Canadian power houses entirely on the Canadian side of the present boundary line.

From time to time and even in recent years, the international boundary between Canada and the United States, at various places, has been modified in such manner as to effect adjustments of mutual advantage to both countries. It will be observed from the Engineering Report and Plans herewith presented, that in the case of the St. Lawrence river certain sites are suggested for power houses which would place the whole of these structures—including Canada's structures—entirely within what is now United States territory. An examination, however, of the positions suggested for these power houses shows that relatively little change of the boundary line would be required in order to place each country's structures on its own side of the boundary, and moreover it will be perceived that where boundary line changes are required, they involve very small areas situated entirely under water or upon which power structures would themselves be situated.

The Commission believes that where problems such as have just been indicated arise they may readily and satisfactorily be solved. The point the Hydro-Electric Power Commission of Ontario desires to make unmistakably clear is that approval by the province of Ontario of power installations such as are shown in the schemes devised and submitted by the Commission's engineers, is absolutely contingent upon the boundary line being altered so as to have the power installations of each country, respectively, constructed and situated upon its own territory.

Development Schemes "A", "B" and "C"

Speaking broadly, two general schemes for the improvement of the upper portion of the St. Lawrence river have been devised and are referred to in the Engineering Report as Scheme "A" and Scheme "B." A third, designated Scheme "C," is a modification of a portion of the main Scheme "B."

The advantages and disadvantages of each method are amply discussed in the Engineering Report.

Ice Difficulties

Certain other engineering aspects of the proposal to develop the St. Lawrence river, such as the subjects of ice difficulties, the securing of fuller regulation, the mode of proceeding with the work, etc., have been dealt with by the engineers both of the Government and of the Commission. These subjects need not here be reviewed. The Commission, however, desires to state that it shares the concern which has been expressed respecting possible ice difficulties. The Commission's engineers in their Report refer specifically to structures being designed and situated so as to cope with ice difficulties. In addition to collecting various data relating to former ice

conditions on the St. Lawrence, the Commission's engineers, during recent years, have made special observations respecting ice manifestations. In the Engineering Report will be found a contribution bearing upon this important subject:—a subject to which the International Joint Commission will doubtless give fullest consideration.

Schemes for Development

Although the international reach of the St. Lawrence can be developed either in two stages or in one, nevertheless, if the former method be adopted, such development, from the standpoint of administration and with respect to flow operation and control, must still be regarded as a unit development.

Scheme "A"

Scheme "A" may be styled the single-head development, because this method would concentrate the entire available fall at the foot of the Long Sault, where the main dams and power houses would be situated. There would also be a control dam at the rapide Plat to regulate the outflow from lake Ontario.

Scheme "A" is very similar to that recommended in the Report of the Government Engineers.

The normal operating head of the proposed power house would be 74.5 feet. At the head of the South Sault channel there would be a power house to utilize, under a head of about 28 feet, that part of the flow of the river diverted to the power plant at Massena, N.Y. The total development would produce about 1,492,000 continuous electrical horsepower at a cost of $141,700,000.

Scheme "A" would require less improvement work for navigation. The total cost of equipment would be less, but this advantage would largely be offset by having to provide other structures such as high dykes. There would be the serious disadvantage of the flooding by backwater of about 29,000 acres of valuable settled land including the flooding of towns and hamlets as shown on the plans herewith submitted.

Scheme "B"

In Scheme "B," the development would be carried out in two stages, the upper of which would include the fall in the Galops rapid and the rapide Plat; while the lower would include the fall in the vicinity of Farran Point and at the Long Sault. The greater part of the fall available in the slope in the intervening river stretches would also be utilizable in either one plant or the other.

Scheme "B" may be styled the double-head development. Two power houses would be built extending from the east end of Ogden island to Clark island and thence to Murphy Point. These would utilize the head of 27 feet

created by the proposed Morrisburg dam. The locations of the dams at the Long Sault in Scheme "B" are the same as in Scheme "A;" and also the power houses on Barnhart island are in very nearly the same situation. The head to be developed at these power houses, however, is 54.5 feet. The total development would produce about 1,600,000 continuous electrical horsepower at a cost of $154,100,000.

Scheme "B" would require less departure from the natural levels of the river, and consequently less flooding. The area flooded would be only about 6,000 acres as contrasted with the 29,000 acres under Scheme "A." About 100,000 additional horsepower could be secured at the Morrisburg site without the extra hazard and cost that would be created by securing this increment under Scheme "A." There is also the important advantage under Scheme "B," of being able to market power about three years before it would be ready under any single-head development scheme.

Scheme "C"

Scheme "C" is also a two-stage concentration to obtain the power head, the upper dam and power house being placed at Crysler island and the lower power house at Barnhart island. This would create and utilize at Crysler island a head of 28 feet. This scheme is identical with Scheme "A" and Scheme "B" as far as Point Three Points. From here to Crysler island no work of importance will be necessary. The work required for Scheme "B" and Scheme "C" below Crysler island is identical. The Engineering Report draws attention to some undetermined factors appertaining to Scheme "C." The total development would produce about 1,635,000 continuous horsepower at a cost of $155,000,000.

With respect to the various development schemes suggested by the Commission's engineers, it should be emphasized that it is not proposed that the whole of the work involved in the selected complete scheme should, once it is commenced, necessarily be pushed forward to an early completion.

Certain portions of any project adopted will, of necessity, have to be carried to the point demanded by governing factors, but in the case of other portions of the work it will only be necessary to complete, as a preliminary, the features required for the needs of the immediate future. Having these facts in mind, the Commission's engineers present estimates of cost both for *completed schemes* and for such *initial developments* as would be suitable to commence with. After the initial minimum development is made, the work required to complete any scheme selected can, of course, be advanced by gradual additions.

Certain initial developments which include all improvements required for deep channel navigation, have been suggested and may briefly be summarized as follows:

SUGGESTED INITIAL DEVELOPMENTS

The initial schemes comprise	Developed continuous capacity in horsepower	Capital cost per horsepower installed
SCHEME A		
All improvements for navigation.		
The control dam at Morrisburg.		
That portion of the main power house at Barnhart island, north of the ice sluices.		
One ice sluice at each end of the main power house.		
An earth embankment with a corewall extending to rock and reaching to 240 contour at Barnhart island.......	735,000	$127
SCHEME B		
Complete navigation scheme from Prescott to Cornwall.		
Power houses and dam at Morrisburg.		
A temporary rockfill dam at the head of the Long Sault..	600,000	$127
SCHEME C		
Complete navigation scheme from Prescott to Cornwall.		
Power house and dam at Crysler island.		
Temporary rockfill dam at the head of the Long Sault....	635,000	$124

Now, inasmuch as the estimated capital costs, per horsepower, of the completed schemes, are in all cases lower than for the initial developments suggested, it is only necessary for the Commission to demonstrate that the cost of electrical energy derived from these initial developments would be sufficiently low to be competitive. Obviously, if this be the case, it necessarily follows that the cost of electrical energy appertaining to the completed development will also be competitive.

Apportionment of Cost between Navigation and Power

Where the improvement of the St. Lawrence river involves expenditures both for navigation and for power, it is obviously appropriate to assign to each use on some suitable basis, the total expenditure involved. When the International Joint Commission has before it all facts, it may recommend some just apportionment of cost between navigation and power which may differ from that which, upon less comprehensive consideration, might appear to be warranted. In estimating what would be the probable costs of power under the different engineering schemes suggested, the Commission's engineers found it necessary to assign to navigation the cost of certain work which would be required solely for that purpose. The manner in which the engineers made this apportionment is indicated in the Engineering Report. The Commission will not here enter into a discussion of this subject, but for purpose of ready reference the table giving "Summary of Estimated Costs" presented below has been made to show, also, the several amounts which, for the purposes of their estimates, the Commission's engineers have apportioned to navigation and to power, respectively, for each of the schemes specifically considered.

Cost of Transmitted Electricity

In the Engineering Report accompanying this Statement will be found a discussion of the costs of each of the schemes submitted. These estimates

are summarized in the following table:

SUMMARY OF ESTIMATED COSTS

Scheme	Continuous capacity horsepower	Total capital cost	Tentative apportionment of costs		Capital cost per horse-power
			Amount for navigation	Amount for power	
Scheme "A" complete......	1,492,000	$209,843,804	$68,147,612	$141,696,192	$95
Scheme "B" complete......	1,600,000	211,466,419	57,373,907	154,092,512	96
Scheme "C" complete......	1,635,000	214,881,524	59,956,109	154,925,415	95
Initial Scheme "A" with complete navigation improvements..................	735,000	161,818,630	68,400,612	93,418,018	127
Initial Scheme "B" with complete navigation improvements..................	600,000	132,542,364	56,132,132	76,410,232	127
Initial Scheme "C" with complete navigation improvements..................	635,000	134,294,464	55,790,364	78,504,100	124
Initial Scheme "A" with 14 ft. navigation only........	585,000	135,980,760	....	135,980,760	232
Initial Scheme "B" with 14 ft. navigation only........	600,000	75,223,785	....	75,223,785	125
Initial Scheme "C" with 14 ft. navigation only........	635,000	79,980,826	....	79,980,826	126

Although the estimated figures printed in this table may, at first sight, appear to indicate advantages or disadvantages for various schemes, nevertheless no conclusions should be deduced without first construing the data of this table in the light of the fuller explanatory comments which appear in the Engineering Report.

For the further guidance of the International Joint Commission, it has been deemed desirable to signify what these capital costs mean in terms of cost per horsepower-year of electrical energy at some distant terminal point of a transmission system conveying large blocks of electrical energy to one or other of the larger cities, in Canada or in the United States.

For purpose of illustration, it may be assumed that a load of, say, 400,000 horsepower is to be supplied over a transmission line 300 miles long at a potential of 200,000 volts stepped down at the terminal of the line to any convenient, pressure, e.g. 12,000 volts. Twenty-four hour power thus delivered at the terminal switchboard would cost from $23.00 to $30.00 per horsepower-year. This means that the electrical energy, based upon a 75 per cent load factor, would cost from one-half to two-thirds of a cent per kilowatt-hour. These figures may be contrasted with the present average cost of steam-electric energy in, say, New York city where,—it is authoritatively stated—the cost is in the neighbourhood of $60.00 per horsepower-year with a load factor of about 50 per cent. Present minimum power rates are about one and one-third cents per kilowatt-hour which means that the cost can scarcely be less than one cent per kilowatt-hour. It is thus evident that electrical power developed from the St. Lawrence River water powers would be able to replace to a large extent steam-electric power.

The Commission has already stated that its engineers had considered a number of schemes for the development of the St. Lawrence river and that these considerations had resulted in narrowing the proposition down to the Schemes "A," "B," and "C" already referred to. Although certain advantages and disadvantages relating to these schemes were emphasized, nevertheless the engineering factors involved appear to demonstrate that from the standpoint of adequacy and capital costs there is little to choose between the single-stage and double-stage developments as represented by Schemes "A" and "B."

Only by viewing this St. Lawrence project in the light of all the essential facts may a sound policy be determined. When all the factors—physical, economical, financial, national, and international—have been assembled, and when to each has duly been assigned its proper weight, then only will it be possible to form a judgment respecting which particular scheme, or combination of schemes, would result in the greatest benefits to the citizens of both the interested countries. Undoubtedly the Welland Canal project, which involves an expenditure of upwards of $60,000,000 will be a factor for special consideration because this improvement cannot adequately be availed of until deep-channel navigation is actually opened through to the sea. The development of water power on the St. Lawrence river will facilitate the attainment of this end. The Commission, in this Statement, has refrained from pronouncing in favour of any definite scheme because it is recognized that by drawing from all possible sources of information the International Joint Commission may bring to light facts as yet undisclosed, but which may justifiably influence the final decision.

In conclusion, the Commission would summarize by stating that in the course of this discussion it has been shown that extensive markets exist capable of absorbing large quantities of electrical energy, and that the water powers of the St. Lawrence river are capable of development to supply these markets. It has further been shown that the St. Lawrence water powers may be developed so as to produce the electrical energy at rates so low as to be competitive and commercially attractive to markets within a range of 300 miles or more of the St. Lawrence river.

The International Joint Commission is called upon to determine whether the engineering and other factors are such as to justify its recommending the development of the St. Lawrence river. Based upon the facts respecting market and power possibilities, as above presented, the Hydro-Electric Power Commission of Ontario believes that your Commission will feel assured that the St. Lawrence river presents one of the most attractive commercial power propositions existing on the North American Continent.

A. Beck

Chairman

Toronto, November 12th, 1921

REPORT

BY THE ENGINEERS

OF THE

HYDRO-ELECTRIC POWER COMMISSION

OF ONTARIO

ON THE

DEVELOPMENT OF THE INTERNATIONAL REACH

OF THE

ST. LAWRENCE RIVER

FOR

POWER AND NAVIGATION

Toronto, Ontario, November 10, 1921

To the Chairman and Commissioners,

Hydro-Electric Power Commission of Ontario,

Toronto, Ontario.

Gentlemen:

The undersigned beg to submit herewith the attached report, with plans, diagrams, estimates, etc., upon the subject of the development, for power and navigation purposes, of that portion of the St. Lawrence river which extends from lake Ontario to the interprovincial boundary line between Ontario and Quebec.

This report is based on data obtained from all previous authoritative investigations and surveys, as well as the surveys and preliminary studies made by the Commission's engineers, and embraces the following specific points:—volume and uniformity of flow; physical features; present state of development; winter conditions; artificial regulation; market prospects and conditions; available power; schemes of development; comparison of different schemes; estimates of cost; apportionment of cost, and conclusions.

We have not attempted to discuss at length the navigation phase of the problem, but have been careful to study and conceive the power development phase in such a way as to insure harmony with any scheme for navigation improvement that may be devised and acted upon. In this connection, we have been assisted by the report of the Government engineers, Messrs. Bowden and Wooten, which was made available to the public by the International Joint Commission, and courteously discussed and explained in detail by the authors themselves. We have, as a result, been able to incorporate in our various development schemes and estimates, such data and limitations as will meet the joint requirements of navigation and power.

We also wish to make the following acknowledgments for data and personal assistance, which were of value to us in the preparation of this Report.

Department of Railways and Canals of Canada; W. A. Bowden, Chief Engineer.

Department of the Interior; J. B. Challies, Director, Water Power Branch.

Department of Naval Service; W. J. Stewart, Chief Hydrographer.

Department of Public Works; A. St. Laurent, Assistant Deputy Minister.

United States Lake Survey; Colonels Wooten, Warren and Churchill.

St. Lawrence River Power Company; J. W. Rickey, Hydraulic Engineer.

New York and Ontario Power Company; W. S. Connolly, President.

And also, for valuable data obtained from the published reports of other investigating bodies, such as the International Waterways Commission, and the Deep Waterways Commission.

We have the honour to be, Sirs,

Your obedient servants,

F. A. Gaby, *Chief Engineer*

H. G. Acres, *Hydraulic Engineer*

R. S. Lea, *Consulting Engineer*

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REPORT

ON THE

DEVELOPMENT OF THE INTERNATIONAL REACH

OF THE

ST. LAWRENCE RIVER

FOR

POWER AND NAVIGATION

I. Studies and Investigations

The problem of developing power on the St. Lawrence river engaged the attention of the Hydro-Electric Power Commission as far back as the year 1906, at which time investigations and estimates were made covering the supply of power to the Ontario municipalities along the north shore of the St. Lawrence river from developments on the canal in the vicinity of the village of Iroquois and from the site of the New York and Ontario Power Company on the Little river at the village of Waddington. Estimates covering the Iroquois development were published in 1907 in the fourth report of the Hydro-Electric Power Commission of the province of Ontario, but as the capacity of this site was only sufficient to meet the more immediate needs of the two municipalities of Prescott and Brockville, the Commission recommended the Waddington site of the New York and Ontario Power Company in New York state as the only source of power available for the supply of a reasonably comprehensive distribution system including the Ontario municipalities between Kingston and Cornwall and north as far as Perth and Smiths Falls. In view of restrictions imposed by the Dominion Government, this development did not materialize, and as a result the problem of an adequate power supply to the municipalities along the north shore of the St. Lawrence river has remained unsolved up to the present date.

When active operations were commenced on the construction of the Welland ship canal, it was generally recognized that the ultimate success of this project must rest upon the subsequent construction of a deep-draft waterway between lake Ontario and Montreal. The importance of power development as an integral part of the St. Lawrence waterway scheme was realized from the first and it was upon the suggestion of the late Hon. Frank

Cochrane, then Minister of Railways and Canals, that the Commission, in 1913, commenced a series of preliminary power-development studies on the international section of the main river itself, which have been carried on continuously up to the present time.

In the spring of 1918 the Commission undertook an intensive study of the power situation on the upper St. Lawrence, involving accurate contour surveys on both shores of the St. Lawrence river between Prescott and Cornwall, foundation explorations in the vicinity of possible sites for dams, extensive sounding operations in the river itself and a comprehensive and continuous study of the variation in water level.

The results of these investigations in further detail are set forth below, and the data thus obtained have been used as a basis for the estimates and recommendations.

General

The field investigations outlined herewith cover that section of the St. Lawrence river which extends between lake Ontario and the boundary between the provinces of Ontario and Quebec. That section which has undergone intensive study is included in that portion of the river between Prescott and the upper end of lake St. Francis and may be designated as the "power reach."

As any study of the river for navigation or power purposes must be based primarily upon the relation between surface slopes and discharge, special stress has been placed upon this phase of the investigation. Numerous gauges were established on both sides of the river, the position of each being determined from a study of the changes in slope in the water surface and other local conditions. The gauges were visited daily and the readings were tabulated and plotted in the form of diagrams. Lock gauge readings and information of a like nature have been secured whenever available, and measurements of the discharge and observations of the slope have been made in the various channels of the river.

Topographical surveys cover the Canadian side of the river between Prescott and Lock 19 of the Cornwall canal; on the American side they extend from the State Hospital opposite Chimney island to the intake of the Massena power canal. Contours, property lines, fences, telephone, telegraph, and power lines and the boundaries of farm and town properties, were located, together with all prominent natural features, orchards, cemeteries, buildings and structures, as shown on the accompanying plans.

Soundings of the river were secured at various governing points with a view to supplementing or verifying the information already available, and to determine the elevation of the rock surface. Well-drill and diamond-drill borings were obtained where it was contemplated that structures might be located.

Numerous maps covering the section of the river under investigation, have been prepared from the surveys. The various data relating to discharge, water levels, etc., have been prepared in tabular form, and the results of the various studies of regulation of discharge, lake levels and backwater for different schemes of development, are shown by diagrams.

Gauges

Staff gauges were established between the head of the Cornwall canal and the head of the Galops rapids. A water-surface profile was first run along both sides of the river, and from the plotted results, and an examination of the river, the location of the gauges was determined. Daily readings of the staff gauges were taken and recorded throughout the open water season in each year. Automatic gauges giving continuous graphic records were located at various points along the river from Lock 27 to below Barnhart island. Portable gauges were operated at critical points on the river to determine changes in stage more accurately than is possible with a staff gauge. The period of operation ranged from a few days to two or three weeks, depending on the changes in stage encountered and the specific purpose in view. The records of the Dominion Department of Railways and Canals were also of great service as they cover daily lock gauge readings for the period 1860 to date. For the earlier part of the period covered, only monthly mean readings at the gauges are now available, but from 1904 to date the records are all daily readings. For the earlier years, the monthly mean readings are based on the noon reading, while latterly, readings were taken at 8 a.m. and 6 p.m. and these form the basis for the daily mean readings.

The staff gauges placed and operated by the Hydro-Electric Power Commission were set to a fixed datum, and the monthly mean elevations deduced. The daily and monthly mean elevations are tabulated on sheets, each of which contains the readings for one year for a single gauge. The record sheets from the automatic gauges are so prepared that blueprints can be taken off the original record. In addition, the hourly record for each gauge has been transferred to a monthly sheet, which contains the records for all the automatic gauges. In preparing gauge relation curves between the various automatic gauges, it has been necessary to take from the records the daily mean gauge height. Gauge-relation curves have been plotted for all the gauges and in the case of those gauges situated at the different locks, gauge-relation equations have been derived for each. Simultaneous gauge readings have been deduced from the gauge-relation curves, and from these the water-surface profiles of the river were plotted. From the lock- and lake-gauge records continuous graphs have been plotted, showing the mean monthly water-surface elevation at each gauge, for the whole period covered by the records.

Surveys

An extensive system of surveys of the territory was made, in connection with which advantage was taken of the presence of the international boundary reference monuments as a ready means of securing a good horizontal control for this system, thereby effecting a great saving of time and effort and eliminating an extensive system of triangulation which would otherwise have been required.

Permanent bench marks had been previously established at various points along the river, and at a majority of the canal locks, by the United States Lake Survey. These were used as a basis for establishing the vertical control of the survey, the elevations of the bench marks being based upon mean sea level, 1903 adjustment. This datum is the one to which are referred nearly all surveys already carried out in the district.

All main traverses forming the skeleton of the surveys were run between the boundary reference monuments and secondary traverses were run from the main traverses to cover the territory under observation. These were both chain and stadia lines, and were always closed on the main traverses to eliminate possible error.

Lines of levels were run in between the United States Lake Survey permanent bench marks along both sides of the river, and bench marks were established approximately one-half mile apart, adjacent to the river shore. On the American side the line extended from the State Hospital opposite Chimney island to the intake of the Massena power canal. On the Canadian side the levels were run from Prescott to Cornwall.

On the Canadian side, and between the head of the North channel and the foot of Farran Point canal, the topography was developed in detail from the river's edge up to elevation 250, and from Farran Point to Lock 19 the contours up to elevation 230 were located. On the American side, from the head of the Galops rapids to Leishman Point, contours up to 250 were located. From Leishman Point to Boice Point, the topography was developed in detail, while between Boice Point and the head of the Massena canal the contours up to elevation 230 only, were located. All the islands, whether in American or Canadian territory, between Croil island and the head of the Galops rapids, were contoured.

A complete survey was also made of the villages of Farran Point, Aultsville, Morrisburg, Iroquois, Waddington, and that part of Cardinal lying below elevation 250. Complete plans of these municipalities have been prepared from the data thus obtained.

During the investigations of the Deep Waterways Commission, some contouring on the American side of the river was done. This related particularly to points where channel improvement was required, notably Galops island, at Sparrowhawk Point, Rockway Point, Leishman Point, in the

vicinity of Waddington and below Louisville Landing. The St. Lawrence River Power Company completed extensive contour surveys of Croil, Barnhart, Long Sault and Sheek islands. The south main shore of the river was also contoured in some detail from Waddington to Richards Landing and these surveys, in conjunction with those of the United States Lake Survey, embrace the bulk of the contour surveys that have been made on the south shore of the river.

On the Canadian side of the river similar data were obtained through the joint effort of the Department of Railways and Canals and the Hydro-Electric Power Commission. The Department of Railways and Canals has contoured in detail the area from the river margin up to elevation 250 from Farran Point to Cornwall, supplementing the information gathered by the Commission below elevation 230 with the exception of a few small areas between that point and the head of the Cardinal canal.

Soundings

Many soundings were made to supplement and verify the data already available. The area covered by these soundings in the main river extends from opposite monument 36 west of the lower end of Ogden island, down-stream to the head of Doran island. The Little River channel from the lower end of Ogden island to Leishman Point was also sounded, together with the channels between Ogden, Canada, Corrigan, and Allison islands, and the main shore. With this information available, it has been possible to develop the subaqueous contours of the river between the lower end of Ogden island and the head of Doran island.

A considerable portion of the sounding was done through the ice during the winter of 1919-20, the area so covered being the Little river and the channels in the vicinity of Canada and Clark islands. The work over the rest of the area was done during the summer of 1920. In the fall of 1919, the Department of Railways and Canals sounded the upper part of rapide Plat and these data have been made use of in conjunction with the United States Lake Survey charts and that obtained by the engineers of the Commission, in compiling a complete plan of the subaqueous contours of the river between Lock 24 and the head of Doran island. The whole of the international reach of the river has been sounded since 1900 by the United States Lake Survey and the results of this work made available from published charts.

Discharge Measurements and Records

At the inception of the surveys a number of discharge-measurement stations were established in various subsidiary channels of the river with a view to determining the distribution of flow under natural conditions. The total discharge of the river has been frequently measured, both by the United States Lake Survey and the Dominion Department of Public Works, and rating tables have been compiled which give an accurate relation between

stage and total discharge. These rating tables were used whenever some knowledge of the total discharge of the river was required in connection with the discharge measurements in the various subsidiary channels. These subsidiary gauging stations were located at the following points: in the American Galops channel between Galops and Dixon islands; between Dixon and Sears islands; between Sears and Baycraft islands; between Baycraft and Twin islands; between Twin and Round islands; between Round and Lalone islands; and between Lalone island and the American shore, these stations being all in the vicinity of the Galops rapids.

Further downstream the following stations were also established. Between Presqu'ile and Toussaint islands; in the Little River channel; between Ogden and Clark islands; between Canada and Clark islands; between Allison island and the American shore; between Doran island and the American shore; between Indian island and Gooseneck island; between Gooseneck island and the American shore; between Strawberry island and the American shore; between Strawberry and Crysler islands; between Crysler island and the American shore; between Croil island and the American shore; and in the Big Sny and Little Sny below Croil island. These stations were operated in the summer seasons of 1918-19-20, a series of measurements being obtained in each season. The range in main-river stage which obtained during the period corresponds to a range of total discharge from 225,000 to 270,000 cubic feet per second.

The United States Lake Survey discharge measurements for the years 1911 to 1914 have been used as a basis for all total discharge determinations. A thorough examination has been made of their records taken at Point Three Points, both in conjunction with the simultaneous gauge readings taken at Point Three Points, and with the various lock and river gauges, which were read at the time of measurement. From a plot of the individual measurements against simultaneous gauge heights, the form of the curve which represented this relation was determined, after which the equation to the curve was derived, both for the Point Three Points section and for the gauge at Ogdensburg. Then by means of the gauge-relation equations between the various gauges, the discharge curve for each lock was determined, and its equation derived. A rating table was then compiled for each of the gauges, and by means of these tables and the monthly mean gauge records the monthly mean discharges were determined. A table of monthly mean outflow from lake Ontario was also compiled, covering the period 1860 to date, and from the lake gauge records, and the table of outflow, a table showing the supply to lake Ontario for the same period has been compiled. These latter tables form the basis of all the storage and regulation studies which have been made in connection with the general scheme.

Borings

Three methods have been used in developing the elevation of the rock surface at various points along and under the river. Where there was reason

to suppose the rock surface was at no great depth below the ground surface, recourse was had to the sounding-bar. Soundings by this method were made through the ice in the Morrisburg canal, around the shore of Portage bay, Ogden island, in the Little river, and at different points in the swale lying back of Rockway Point. During the early part of 1919, a well drill was secured and a number of holes were put down along the bank of the Morrisburg canal, west of the town of Morrisburg, opposite Canada island, both on the canal bank and on the main shore, and on Canada island itself. In order that the rock surface might be developed in greater detail, and a better idea obtained as to the nature of the rock itself, a contract was let in the fall of 1919 to a diamond-drilling firm. Under this contract over fifty holes were put down, both on the land and in the river, on a line extending between the Pulp Company dock on the American shore, and a point opposite Canada island on the Canadian shore. Each hole was put down at least forty feet into the rock. The rock cores were classified geologically, so that very definite information has been compiled in the form of a vertical section of the rock along the line of the borings, and the log of each hole prepared in the form of a chart.

In addition to the above data, the well-drilling data obtained by the Department of Railways and Canals have been obtained and made use of, as have also the data secured previously by the Deep Waterways Commission.§

Backwater Studies

Studies of backwater conditions in the river form the primary basis for any improvement, either for navigation or for power development. On this account considerable time has been devoted to this phase of the investigation. As backwater studies are primarily dependent on cross-sectional areas and surface slope, these two factors have been determined with considerable care. The surface slope of the river for different sections was determined from the simultaneous gauge heights, and cross sections, at intervals of 1,000 feet, were developed from the contour plans of the river, the area and the hydraulic radii being determined for various water-surface elevations. With the aid of these determinations, curves of area and hydraulic radii were plotted for each section. Values of the "roughness factor" were then worked out for various discharges in the different sections of the river, and a series of backwater computations was made covering a range in total discharge from 190,000 c.f.s. to 290,000 c.f.s. and for various assumed conditions of channel improvement.

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§A large number of additional diamond-drill borings are being secured by the Hydro-Electric Power Commission, and this work is still in progress.

Note: In preparing for the printer the copy of the original manuscript of this Report as submitted to the International Joint Commission, a few instances were observed where an added word of comment would aid the reader. Consequently, a few footnotes have been supplied. The supplementary notes thus added are designated by the symbol §.

II. Characteristics of the St. Lawrence River from the Standpoint of Navigation and Power Development

Under this heading are presented, for convenience, certain distinctive characteristics of the St. Lawrence which have an important bearing on many of the problems connected with the improvement of the river for navigation and power, and which in some cases constitute controlling factors in the construction and operation of the necessary works.

Uniformity and Volume of Flow

The St. Lawrence from lake Ontario to its junction with the Ottawa, is not a river at all in the sense that its discharge is directly dependent upon the precipitation on its adjacent drainage area.

The total area included within the watershed of the Great Lakes system as far down as the foot of lake Ontario is, in round numbers, about 300,000 square miles, while the area directly tributary to the stretch of the St. Lawrence under consideration is only about two per cent of this. Hence, for all practical purposes the river may be considered as simply the overflow channel of lake Ontario.

Of the total drainage area of 300,000 square miles just referred to, less than one-eighth is directly tributary to lake Ontario. The balance of the supply to the lake flows into it through the Niagara river, which is subject to the natural regulation of the storage capacity provided by lakes Erie, Huron, Michigan, and Superior. Hence, the supply to lake Ontario is of necessity extremely constant, and free at all seasons from any considerable or sudden fluctuations.

The lake is itself a huge reservoir or regulating basin, 7,500 square miles in extent, with a lip or overflow at its eastern extremity and provides sufficient storage capacity to receive the entire average inflow from the Niagara river and the run-off from its own drainage area, with a rise of a little over one inch per day, even with the discharge down the St. Lawrence entirely stopped.

The outflow of the lake is actually controlled by the ridge of hard rock which crosses the bed of the river at the head of the Galops rapids, about five miles below Ogdensburg and Prescott, and the flow of the St. Lawrence river is dependent solely upon the elevation of the water above the crest of this ridge. From the foot of the lake to Prescott, on account of the great depth and cross section of the river channel, the velocity of flow is very low and the surface slope so slight as to be almost negligible, being less than one-quarter of an inch per mile. This 60-mile stretch of the river may therefore be looked upon as an extension eastward of the lake, so that the discharge of the St. Lawrence is really governed and measured by the elevation of the water surface of lake Ontario.

The resultant effect of the combination of conditions above referred to, in producing uniformity of outflow, is clearly shown by the records and observations of the past sixty years. During this period the highest recorded level at the Oswego gauge was 248.95 in May, 1870, and the lowest 243.41 in November, 1895, or an extreme range of about 5.5 feet. The corresponding change in the volume of outflow was from 193,000 to 320,000 second feet, or a total range of 127,000 second feet. This indicates an average increment of discharge of 22,700 second feet per foot rise in lake level. It is not quite uniform, however, but varies from about 21,000 second feet at extreme low water to about 24,000 at the maximum stage. Since the dates above referred to, the Gut dam at the head of the Galops and the Chicago drainage canal have been built, and the figures quoted have been slightly changed in consequence. Under the conditions as they exist for the greater part of the time, however, it is correct to say that a change in elevation of one foot in lake Ontario will cause a change in the discharge of the St. Lawrence river of between 22,000 and 23,000 second feet, which is equivalent to eight or nine per cent of the average and ordinary flow.

It should be stated here that the minimum flow mentioned above refers to months of open water. In a few winter months the discharge has fallen lower, in one case to about 184,000 second feet.

The average discharge of the river during the period observed is about 247,000 cubic feet per second, so that the extreme variation is less than thirty per cent either way from normal, and the maximum is considerably less than twice the minimum, which is a most remarkable record, even if applicable to a single year, instead of to a period of sixty years. As a matter of fact the maximum fluctuation in the elevation of the lake in any one year was 3.7 feet, in 1867, and in only four different years did it exceed three feet.

In 1907 the extreme range was only eight-tenths of a foot, and for years at a time it varied between one and two feet only. The mean range of level over the whole period is less than two feet, which means that, on the average, the rate of discharge in any one year varies less than ten per cent either way from the average of that year. An examination of the records will also show that very seldom indeed does the average discharge in any year differ by more than ten per cent from that of the preceding year.

The monthly and yearly fluctuations in river level naturally follow those of the lake, though the range is not always the same, being at some points a little greater, and in others a little less, depending upon local conditions as to width, depth, and velocity of current. During the winter months, however, at certain points a rise in level takes place every year to a greater or lesser degree, caused by back water from ice jams.

The figures quoted in the preceding paragraphs are monthly means and so will differ a little from the records of individual days. But the differ-

ence is, in general, so slight that the monthly means may be assumed to represent the actual conditions with substantial accuracy. It should also be noted here that a series of records covering such a long period, and of so comprehensive a character, furnish data incomparably more complete and valuable than have ever been available elsewhere.

In order to emphasize the unique character of the St. Lawrence in respect to stability of flow, reference may be made first to the Ottawa river, which, next to the St. Lawrence, is the largest river in eastern Canada, and which has a comparatively regular discharge owing to the presence of numerous lakes within its drainage area; and, second, to the Susquehanna river, which is an example of a river liable to excessive fluctuations of flow.

The Ottawa records have been kept since 1850, but the following figures do not include those of the last few years during which artificial regulation has been employed. The average flow was about 55,000 second feet; the minimum flow was as low as 8,000 to 10,000, while at times of high water the discharge varied on several occasions from 190,000 to 200,000, and at one time reached a maximum of 250,000 cubic feet per second.§

The Susquehanna for a period of about sixteen years averaged nearly 39,000 second feet, with a minimum of 2,400 and a maximum of 540,000. In four years out of the sixteen the discharge exceeded 300,000 second feet and in 1902 for three consecutive days the flow averaged over 480,000.

The ordinary flow of these rivers is much less than the average on account of the exaggerated effect of the excessive flows during the periods of high water. In both, the water level frequently rises during floods 15 to 25 feet or even more. On both there are important water-power developments which have had to be constructed so as to be primarily suited to the minimum and ordinary flows, and at the same time to be capable of taking care of flood flows many times greater.

All of this demonstrates forcibly the unique dependability and steadiness of flow of the St. Lawrence; an important consequence of which is that it becomes possible to estimate the probable effect of works, designed to cause change in level or in the natural flow, with far greater accuracy than can be done in the case of other rivers.

The drainage area of the St. Lawrence being over 300,000 square miles, places it at once among the large rivers of the world, although it is far from being the largest in this respect. The drainage area of the Missouri, for example, is 528,000 square miles; of the Mississippi, 1,244,000 square miles; and of the Nile, 1,500,000 square miles. With respect to its ordinary and low-water flows, however, it ranks among the first, and it is probably correct

§These figures represent the discharges of the Ottawa river at Besserer's Grove, just below the city of Ottawa.

to say that its dependable flow is greater than that of any river in existence which is adapted to power development.

In the light of the above comparisons, there is no need to dwell upon the value of the great volume and regularity of discharge of the St. Lawrence river for power and navigation purposes, from the standpoint of both construction and operation, or to further emphasize the practically absolute reliability of the evidence upon which the vital factor of power capacity may be computed. The development of such a large flow under the moderate heads available will necessitate power houses of much greater dimensions than have ever yet been constructed, but the works as a whole will not differ materially in conception or design from a number of plants which have been installed in recent years.

On account of the exceptionally large flow of the river, even at its lowest stages, the placing of coffer dams will involve work of unusual magnitude, and in some locations, of unusual difficulty. It is, however, chiefly a matter of depth of water and velocity of current, as the steadiness and dependable character of the flow and the narrow range of the possible fluctuation in level, remove what is usually found to be the most serious of the difficulties encountered in the carrying out of projects of this kind, and wherein exists a point of the greatest uncertainty both as to the cost of construction and the length of time required to complete; this being the liability of sudden freshets to cause excessive rises and the flooding out of the entire works, resulting in expensive delays, and injury to plant and structures.

There are, as has already been stated, certain places in the river where backwater due to ice jams is liable to raise the water level to a more or less serious extent every winter. In this connection, however, it should be pointed out that whatever scheme of development is adopted, an essential feature will be a dam capable of controlling the discharge of the river, and located in the rapide Plat, a short distance above Morrisburg. The local conditions at this point are favourable for the construction of such a dam, and it should be the first work undertaken in the general scheme of improvement, largely on account of the protection from ice and the facilities which it would afford in other ways, in the carrying out of works lower down.

Moreover, investigations show that sites are available for these developments where the power houses and much of the other work may be constructed in quiet water, without interfering in any way with the flow of the river, and where a large proportion of the flow may be diverted while the closing dam is being built.

Physical Features of the St. Lawrence Channel from Lake Ontario to Montreal

After passing through the Thousand islands at the outlet of lake Ontario, the river follows a straight north-easterly course to Prescott and Ogdensburg, in a channel almost without perceptible surface slope and which is virtually

an arm of the lake. From there to Montreal, a distance of about one hundred and twenty miles, it falls a vertical distance of about two hundred and twenty-five feet. The river does not follow any well defined valley, but flows in a comparatively shallow depression over and across the territory which lies between the western spurs of the Adirondacks and the valley of the Ottawa River, towards which there is a slight northward slope transverse to the direction of the river. As a result of this, the Ottawa River divide is never far from the St. Lawrence, the tributary drainage area of which is therefore mainly on the south side of the river.

In the direction of flow, however, the land falls in a series of three main steps or terraces with comparatively level benches between. These terraces intersect the river in a generally north and south direction, at the Long Sault, at the head of lake St. Louis, and at the Lachine rapids near Montreal. Down as far as the Long Sault, the fall of forty feet or so in the land surface takes place more or less gradually. The river profile closely follows the surface of the land, and as a result of the topographical conditions referred to, the total fall takes place in three distinct reaches, separated by the river expansions of lake St. Francis and lake St. Louis. They are:

(1) From the head of the Galops to the foot of the Long Sault.

(2) From the head of the Coteau rapids to the foot of the Cascades.

(3) From the head of the Lachine rapids to Montreal harbour.

In these reaches, which will be referred to hereafter as "power reaches," the river descends in a series of rapids which occur at points where an outcrop of bed rock crosses the channel of the river.

In the upper reach from Prescott to Cornwall, a distance of nearly fifty miles, there is a total fall of a little over ninety feet. About half of this takes place in the Long Sault and the balance in the Galops rapid, the rapide Plat and Farran Point rapid, and in the swiftly flowing stretches of the river intervening. Between eighty and eighty-five feet of this fall can be utilized for power development.

Between lake St. Francis and lake St. Louis, in a distance of about fifteen miles, there are three rapids—the Coteau, Cedars, and Cascades, with a total fall of about eighty-two feet, of which about seventy-five feet is available for power.

Between lake St. Louis and Montreal harbour the total fall, including the Lachine rapids, is about forty-five feet, and of this from thirty to thirty-five feet can be developed for power according to the stage of the river.

Transverse to the river the country is nearly level but in the upper reach, where the surface is gently rolling, there is a pronounced slope in the general direction of flow, and as a consequence most of the tributaries tend to follow a course parallel to, and at no great distance from, the river itself. Hence along the lower part of this stretch of the river it is impossible to raise the

level by dams to any considerable degree without extensive dyking to prevent overflow, not into another drainage area, but into tributaries of its own which enter it further down and at a lower level.

In the two lower reaches the country bordering lake St. Francis and lake St. Louis is very flat, and so low as to render impracticable any elevation of the water above the maximum now existing. So far, therefore, as the construction of works for the development of power or navigation is concerned, these lake expansions may be left out of account, as the only improvement necessary is a very moderate amount of additional dredging which may be required at some points to provide for navigation. In the matter of the operation of these works, however, they play a very important part. For example, if it were not for the existence of the two lakes just referred to, and lake St. Peter below Montreal, the river from Prescott to tide-water would not freeze over, but would remain open at all seasons of the year. There would be no regular recurrence of winter and spring floods due to backwater, at Montreal, at the head of lake St. Louis, and at Cornwall, and the most difficult problem in the development of power on the river would be practically eliminated.

Climatic Conditions

The period of the year in which climatic conditions on the St. Lawrence have an important bearing on the questions of power development and navigation, is that which includes the months of December, January, February, March and April. The entire distance covered by the portion of the river under consideration is not great enough, under ordinary circumstances, to imply any appreciable difference in mean temperature, but in this case the moderating influence of the large body of water in lake Ontario is effective, in a diminishing degree, for a considerable distance eastward. A reference to observations covering a long period indicates that the minimum temperatures in December and January are from five to six degrees lower in the vicinity of Montreal than at Kingston. In the other months the difference is about half as much. It is, therefore, probably fair to say that in the upper portion of the river, during the coldest months of the winter, the climatic conditions are somewhat less severe than in the lower stretches, and that the difference is sufficient to warrant the expectation that operating conditions during the winter will be correspondingly less difficult and less expensive.

Power and Navigation on the St. Lawrence

The special concern of the Hydro-Electric Power Commission of Ontario in the St. Lawrence river is naturally the question of power, and it has been interested in the partial development of the rapids which are located within the boundaries of the Province, for a number of years. The investigations of the last three years, however, upon which the present report is based, have been carried out for the purpose of obtaining information as to practicable

methods of developing the power of the entire flow of the river, and in connection therewith the paramount importance of navigation has always been kept in mind, and the primary necessity of providing for its requirements fully recognized.

Since the date of the reference of the whole question of the improvement of the river to the International Joint Commission, the engineers of the Hydro-Electric Power Commission have had an opportunity of co-operating to some extent with the engineers appointed to study this matter by the Governments of Canada and the United States, and at the same time to obtain detailed information regarding the character of the river improvements and the type of locks and other structures, which would be considered as satisfactorily providing for navigation in any schemes which involved the canalization of the river and the simultaneous development of power. Under the conditions as they exist in the international portion of the river, it has proved to be a simpler matter to fulfil all the requirements of navigation than those of power development, inasmuch as the actual operation for navigation is confined to the season of open water, and consequently the serious difficulties involved in dealing with the ice are almost entirely avoided. Hence, while the interests of navigation are paramount during the navigation season, the actual location and design of controlling structures must be largely governed by the necessity of safely handling and regulating the winter flow and of controlling ice conditions.

The present fourteen-foot navigation between Prescott and Montreal is maintained by a system of side canals and locks where open-river navigation is not feasible.

The power already developed on the St. Lawrence amounts in all to about 300,000 horsepower of which over 200,000 horsepower is on the Canadian side of the boundary, and of which the greater part has been installed within the last six or eight years. New equipment, which it is planned to install within the next two or three years, will add an extra 60,000 horsepower to the capacity of the Canadian plants.

The total power which can be developed in the river in the three power reaches referred to in a preceding paragraph, amounts in round numbers to about 4,000,000 electrical horsepower of twenty-four-hour power of which about one-sixth can be obtained from the lower reach, and the balance in about equal amounts, from the two upper reaches. The report of the Government engineers to the International Joint Commission shows that in the two lower reaches, which are included in their first and second divisions, the local conditions are unusually favourable for the use of locks and side canals for navigation, with the important feature that the work can be carried out quite independently of the development of power, which can be dealt with as a separate propositon either simultaneously or at a later date.

The upper reach, on the contrary, is particularly adapted to improvement by the canalization method, and it would be an engineering and economic mistake to adopt lateral canals of great length and cost, quite apart from the inferior navigation facilities which would be thus afforded. Accordingly the Government engineers have recommended canalization with the incidental development of power, as the proper method to be employed, and the improvement of this stretch thus presents an entirely different problem from the remainder of the general scheme.

There are several other reasons why this particular section of the river should be dealt with as a unit in itself, and in a separate category from the rest. For example, it is the next step, following in natural sequence the completion of the new Welland canal, in the general project of providing a system of deep-draft navigation from Montreal to the head of the Great Lakes, and will in itself bring this system to within forty miles of Montreal. It comprises at once the international section of the river, and the whole of that portion which lies entirely within the boundaries of the province of Ontario. The drowning out of the rapids should begin at the upper end of the river on account of the protection from ice thus afforded in connection with both construction and operation of works lower down, and because of the improvement to navigation down the entire river through Montreal harbour to tide water, which will result from the regulation of the flow which is involved in such a development.

The improvement can be carried out in accordance with two general schemes, which may be referred to as the methods of "double development" and "single development." In the former, the works would be carried out in two stages, the upper of which would include the fall in the Galops rapid and the rapide Plat, and the lower that of the Farran Point rapid and the Long Sault. The greater part of the slope in the intervening river stretches would also be made available in one plant or the other. By this method the river would be confined, to as great an extent as practicable, within its present banks, with a minimum of flooding from backwater.

In the "single development" scheme it is proposed to concentrate the entire available fall at the foot of the Long Sault where the main dams and power houses would be located. There would also be a control dam at the rapide Plat to regulate the outflow from lake Ontario. On account of the character of the lands bordering the river, which has been previously described, this method would involve the construction of long and high wing dams or retaining walls and a large number of dykes of various heights. It would also cause extensive flooding in and below Morrisburg, including most of the farm houses and villages as far down as Dickinson Landing.

Each method has certain advantages and disadvantages, which are dealt with in the more detailed descriptions given in another part of this report.

III. Winter Conditions

Present Conditions

The discharge of the St. Lawrence, even without any artificial regulation, is so steady, and the fluctuations in level day in and day out, are so slight, that so far as the flow in the open-water months are concerned, the conditions for constructing or operating a power plant or navigation canal are unequalled, and may be fairly characterized as almost ideal.

During the winter months, however, this is not everywhere the case. As a general thing, in the stretches of the river which remain open at all times, there is little or no disturbance. The then existing level may be at times a few inches higher than the summer level for a corresponding discharge, but usually the slope is not appreciably affected, though small temporary changes may occur occasionally, due to an unusual growth of anchor ice, or to its sudden liberation.

The open-water stretches to which these remarks apply include the stretch from Prescott to the Long Sault, from lake St. Francis to the foot of the Cedars rapids, and through the lower half of lake St. Louis to the Lachine rapids. Lake St. Francis, though it always freezes over, should be included, since its level is also practically unaffected in winter.

Reference should be made here, however, to certain exceptions to these general statements which have occurred in the past.

At long intervals the backwater from the ice jams at Cornwall has affected the river levels as far upstream as the head of Farran Point canal, and on three or four occasions in the past fifty years, floods due to backwater have been caused as far up as Morrisburg, by ice-bridges swung purposely across the river between Croil island and the Canadian shore. But these exceptions are rare, and it may therefore be stated generally that in the whole stretch of the river from Prescott to Montreal, the levels and slopes are not appreciably different in winter from what they are during the remainder of the year, except at the foot of the Long Sault, the Cascades, and the Lachine rapids. At these points there is a regular winter rise, the extent of which depends somewhat on the severity of the winter, but chiefly on the simultaneous occurrence of various adverse factors. In every case this rise is due to ice jams, which always occur in the St. Lawrence wherever an open stretch of river joins one over which a solid ice cover has completely formed.

In the case of the Lachine rapids the original jam occurs among the shoals and islands at the head of lake St. Peter, which is the first part of the river to freeze over completely. The ice-bridge thus formed arrests the floating ice, which at first may be supplied from the whole river as far up as Prescott. As it accumulates the water rises, and as the cover of packed ice builds upstream, new jams are formed at certain constricted points below

Montreal, and in front of the city, sometimes backing the water nearly half-way up the Lachine rapids.

At the upper end of lake St. Louis, where the next jam occurs, the channel is wide and deep, and the rise is ordinarily not over six or eight feet in height, but occasionally, as in 1918, it is sufficient largely to drown out the Cascades and Split Rock rapids, and raise the river level up to the tailrace of the Cedar Rapids power-house.

After the ice forms in lake St. Francis, jams soon begin to accumulate in similar fashion at the upper end of the lake and the ice pack extends up-stream to Cornwall and beyond. In the narrow and shallow stretch between Locks 17 and 18, "shoves" occur, with alternate rising and falling of the water. The channels around and between the islands become choked, causing the water above Cornwall island to rise still higher. In 1918 the water rose at the foot of Barnhart island for a short time to within twelve or fourteen feet of the normal level above the Long Sault. This backwater is primarily due to the jams at the head of lake St. Francis but the effect is greatly enhanced by the shoves and secondary jams caused by the natural obstructions in the river channels above, which have just been referred to. Improvements can, however, be readily made at this point which will, in themselves, undoubtedly provide considerable relief and greatly reduce the height of the floods.

While the main channel of the river from above the Galops to the Long Sault always remains open,§ a considerable area of bordage ice forms in the bays and subsidiary channels, and where slack water and eddies occur in the lee of the islands. The result is that in ordinary winters there is sooner or later a solid sheet of marginal or bordage ice covering nearly a third of the total water surface. This process usually begins in the early part of December, but is frequently interrupted, while the ice is still thin, by the action of the wind and by sudden changes in level. As a matter of fact, solid sheet ice does not readily form on the St. Lawrence, even in the coldest weather, due partly to the unusually large amount of residual heat which must first be radiated.

In the stretch between Prescott and lake Ontario, where the velocity of the current seldom averages more than half a mile per hour, it usually freezes

§That is to say, under normal conditions. At intervals of several years—the last two or three ice jams have recurred at intervals of about 18 years—a field of border ice has swung into the open stream. Usually such border ice has been released artificially in order to form a temporary bridge. During February of 1923, a serious jam caused by border ice occurred in two sections of the river. The upper jam extended from the foot of Gooseneck island to the foot of the Morrisburg canal. The foot of the lower jam was between the lower end of Croil island in the international channel and Weaver Point. A field party was placed on the ground early in February, 1923. This party established a number of staff gauges, observed water levels, compiled a history of the jam and observed the movement of the ice. Additional valuable information is now available respecting the growth and extent of this jam. There is, also, available other related information such as water-surface slopes, discharge, etc., that will be valuable in connection with designs for protection from ice.

over, but in many winters it only remains closed for a comparatively short time, and the ice in mid channel seldom attains any great thickness and frequently opens up with the advent of a period of mild weather. In one winter, not long since, it practically never froze over at all.

Even after it has attained considerable thickness, a January thaw, with several days of mild weather, will sometimes cause considerable portions of the bordage ice to break up or become detached and float down the river in the form of fields or floes. In mild winters or in winters in which periods of severe weather alternate with warm periods, this break-up may happen more than once.

When long-continued cold has made the ice so thick and strong as to be no longer in danger of being broken up again by a thaw, or by winds, it gradually extends outward, encroaching upon the main channel until a point is reached where the adjacent surface velocity is from two and one-half to three feet per second, at which point the formation practically ceases. In portions of the river where the channel velocities fall below two feet per second, a protracted period of severe weather will cause the ice cover to extend from shore to shore, but unless such a condition obtains, all floating and drift ice, of whatever nature, will pass continuously downstream through an open channel.

Ice of a different kind, however, continues to form in the open-water stretches, throughout the winter. Frazil forms in open water during periods of intense cold, particularly at night and in cloudy weather. Anchor ice forms in open water on the bottom in clear cold weather, and especially where the channel is comparatively shallow and the current rapid. In the turbulent water of the rapids, both kinds form very readily even when the weather is only moderately cold. Fragments of bordage ice detached by the wind and currents, and, during heavy snow storms, drifting snow, add intermittently to the icy burden of the river. It is the frazil and anchor ice, however, which cause the jams, and of the total quantity of such ice produced in the course of the winter, by far the greater part is formed in the Galops rapid, the rapide Plat, and the Long Sault. In the remaining stretches, where the river flows smoothly and with unbroken surface, the quantity of frazil produced is proportional to the area of open water exposed during periods of severe cold and high winds. The formation of anchor ice depends also upon the area of exposed surface where the depth is less than twenty or twenty-five feet, and where the velocity is comparatively high.

The total area of the water surface between Prescott and Cornwall amounts to about thirty-two square miles, and during an ordinary winter about ten square miles of this is covered with bordage ice. Since frazil and anchor ice formation depends so largely upon the extent of open water, it is plain that the two chief controlling factors which affect, directly or indirectly, the production of ice of different kinds, in such an area as this, are the velocity

of the current, and the depth of the water. In the navigation reaches, that is, apart from the rapids, the depth of the main channel usually varies from thirty-five to fifty feet or more. The volume of the discharge of the river is so great, however, that in spite of the unusual depth and width, the velocity of the current is always very high. From the head of the Long Sault to Weaver Point the average velocity is from two to three feet per second. From there to the foot of the rapide Plat it varies from four and one-half to eight feet per second and from the head of Ogden island to the foot of the upper Galops it varies from two and one-half to eight and one-half feet per second. These are average velocities and therefore do not represent the actual velocities as they occur in the river. A large number of current meter measurements have been made at different points along the river and at various depths, and these show that in the main channel the velocities usually range from forty to fifty per cent above the average.

Conditions after Proposed Improvements

In connection with schemes for developing this section of the river, which entail the raising of the water surface by the construction of dams, attention should again be directed to certain points in which it differs from other rivers. For example, in the two-hundred-mile stretch of the Ottawa river above its junction with lake St. Louis, the surface width is as great as that of the St. Lawrence, and even in the narrower reaches it is usually from one-third to one-half as great; yet its ordinary flow is not more than one-eighth or one-tenth that of the St. Lawrence. The main reason for this disparity is the fact that while the ordinary flow of the Ottawa varies from twelve to twenty-five thousand second feet,§ its channel frequently has to carry flood flows which approximate one-half to two-thirds of the maximum flow of the St. Lawrence. The result of this great difference in conditions between the St. Lawrence and the Ottawa, and other rivers as well, becomes manifest when the river is raised by the construction of dams.

The ordinary channel depth of the St. Lawrence river is from thirty-five to fifty feet and the banks of the river are steep, and as has already been explained, it is not practicable to raise the level of the river very far above its natural banks. At the head of the Long Sault for instance, the maximum possible rise in the surface level will be about forty feet, and the limitations imposed by the water level of lake Ontario will likewise restrict the maximum increase in depth between Farran Point and the foot of the rapide Plat to from thirty to thirty-five feet, and above the rapids to about fifteen feet at Lock No. 24, and to two feet, more or less, at the head of the Galops. Hence, it will be seen that nothing in the nature of a true pond or "lake-like expansion" of the river can ever be caused by the construction of the highest possible dam, except in the vicinity of the dam itself, and for a comparatively

§See footnote on page 50.

short distance upstream. At the same time, the increase in depth and cross section will not be sufficient to prevent comparatively high velocities, particularly in the upper part of the river; and it has been shown above that the behaviour of the improved river, under winter conditions, will depend very largely upon the extent to which these velocities will finally be reduced under the various proposed schemes of development.

There is another point also to which attention should be directed in connection with the question of ice troubles. Every year, at the onset of cold weather, the whole stretch of the pool and river above the dams will, at first, be almost entirely free from ice cover and while the permanent bordage ice is forming, there will be a period, sometimes lasting for weeks, when a comparatively large proportion of the surface will remain open. This period is the coldest time of the year, with the shortest days, the least sunshine, and when the sun has the least power. The conditions are then especially conducive to the formation of frazil and anchor ice, and it is at this time that a very large part of the material is produced which forms the jams at Cornwall. This circumstance should be seriously taken into account when considering the relative merits of different schemes of developing the river, in respect to the ice problem.

It has already been stated that the greater part of the total quantity of anchor ice and frazil produced in the course of the winter at the present time is derived from the rapids. Hence, any scheme of river improvement which involves the drowning out of these rapids, will by that means alone remove the agency which is responsible for the larger part of the accumulations of frazil and anchor ice which form the jams at the head of lake St. Francis.

The difficulties involved in the winter operation of power plants, control dams, etc., may be divided into two main classes, viz. (1) those which may arise when all of the ice in the river is in motion, a condition that may occur in the early part of the winter as a result of winds and thaws, and in the spring when the permanent winter ice cover breaks up and is carried downstream before it has time to melt. (2) Those which may occur after a permanent ice cover has formed, and when only anchor ice, frazil, slush, and small cakes of sheet ice, are carried by the current.

Another classification may be made, depending upon whether the troubles are in connection with the power house and approaches, or in the river itself, either above or below the plant.

The general layout and location of the power houses themselves, and the dams and sluices, should be such as to avoid to the greatest extent possible, the possibility of floating ice gaining access to the forebay. Running ice is greatly influenced by even light winds, and tends to follow one side or the other of the channel when the wind is not approximately parallel to the direction of flow. Whenever possible, therefore, the power house and ice sluices should be so placed that when the wind is in one direction, the running

ice will tend to pass over the dams or through the sluices without entering the forebay at all, and when the wind is in the opposite direction, the effect should be to keep the ice away from the entrance to the wheels. With proper provision of this sort, any floating ice which may reach the power house can be taken care of without difficulty, by skimming booms and similar devices with which modern power plants in cold climates should be equipped; or at worst, any frazil, anchor, or slush ice, which might pass these barriers and reach the racks, can easily be dealt with by raising the racks and allowing it to pass through the turbines, which, in the plants under consideration, will offer no effective obstruction, on account of their large size.

The troubles which may occur in the river above and below the plant are mainly due, first, to jams in both locations, causing a rise in level in the tailrace, or a drop in level in the pools; the result in either case being a reduction of head at the plant, and a consequent falling off in power; second, to the formation of a complete ice cover in the river above, where the speed of the current will permit, which ice cover will, if at all extensive, consist largely of packed ice, often of great thickness, and with an extremely rough under surface. The resistance of such an ice cover to flow will be very great and will cause a permanent lowering of the forebay level to such an extent as to seriously reduce the winter output of power.

A jam is caused by the accumulation of ice in front of, and beneath, a continuous ice cover, with a stretch of open water above it. Ordinarily, the result of this is to cause a rise of water above the jam which continues until the velocity is sufficient to force the flow through the obstructed channels. There are, however, certain points in the river where the channel is very shallow and narrow and the ordinary velocity very great, as for instance, at Montreal, and in the river at Cornwall between Locks 17 and 18. When a jam forms under conditions such as obtain at these points, "shoves" take place which carry the jam bodily down the river until arrested at a jam lower down. These "shoves" may be repeated several times, the effect being to ram the ice into the lower constricted section until it is plugged so tightly as to cause an excessive rise in water level, as compared with jams formed where "shoves" do not or cannot occur.

The loss of head, or increase in slope, is very much greater where the river is completely bridged by ice, than where a channel in mid-stream remains open. Special investigations, made with more than half the surface covered with bordage ice, show that it has but little effect on the slope of the river. This fact is confirmed by the regular winter readings of the permanent gauges. The reason is that even under open water conditions the bulk of the flow is carried in the main channel where the depth and velocities are much the greatest. When an ice cover forms in the slower currents and shallower water along the shores, the increased resistance forces a portion of the shore flow out into the open mid-channel until the slopes mutually adjust themselves, such adjustment taking place with only a slight increase in the slopes which

existed before any ice was formed. As a matter of fact, experience so far gained in connection with power developments on the St. Lawrence, indicates that the only successful method of preventing undue loss of head through ice resistance of this kind is to maintain an open channel of moderate width throughout the entire length of the affected section and down to the ice sluices at the power plant itself.

No attempt will be made at this point to compare the different schemes of improvement with respect to the difficulties arising through the formation of ice. Attention will, however, be directed to certain points of importance in this connection, which must be considered and carefully weighed in all their bearings, and in the light of experience. They are as follows:

(1) The increase in the area of water surface occasioned by the construction of dams.

(2) The resultant slackening of the current in the different channels of the river.

(3) The extent of shallow flowage and bays, which favour the formation of bordage ice.

(4) The difficulties in construction due to the ice hazard.

(5) The relative effects of ice jams in causing a reduction of the head at the dams and consequent shortage of power, and in the possibility of the occurrence of jams which may cut down the discharge of the river.

Objections have been raised and doubts expressed regarding any project involving the damming of the whole river. These apprehensions are not based on any specific grounds, but are connected in a more or less indefinite way with its great volume of discharge. There is a feeling that the effect of interfering to such an extent with the flow of this mighty river may result in consequences which cannot be predicted or determined in advance. Consideration of actual circumstances arising out of the facts disclosed by study and investigation will, however, show that this uncertainty is more apparent than real. For example, with regard to the maximum possible height of backwater which may be caused by the dams themselves, or by obstructions from ice, or from whatever cause, the maximum elevation is absolutely limited in this upper reach of the river by the elevation of the water in lake Ontario. This simply means that water can never rise, under the most extreme conditions imaginable, to a higher elevation than, say, two hundred and forty-six feet, and by reference to the contour plans of the district it can readily be seen that it is possible to take care of elevations considerably higher, especially upstream from Farran Point. As a matter of fact, it is planned to maintain the working level of the river, down at least as far as Morrisburg, between elevation 240 and 242, with ample provision for a water level several feet higher.

It has already been shown that the unique relationship between the maximum, minimum and normal discharges of the St. Lawrence is directly due to its extraordinary steadiness and regularity of flow, which very largely smooth out all fluctuations either above or below the average; and that, under open-water conditions, this feature, of itself, enables the St. Lawrence river to be controlled and utilized with greater facility and freedom from uncertainty than is attainable in other rivers of large size.

It must furthermore be kept in mind that while the ordinary flow of the St. Lawrence is very great, it has no floods or freshets, or indeed, anything in the way of high water in the usually accepted sense. Its maximum flow in any year is never as much as twenty per cent above its mean flow, and the increase and decrease in flow takes place very gradually. Floods of six or eight times their ordinary flow are common in most rivers, and the discharge of rivers like the Missouri, Upper Mississippi, or Susquehanna, for example, which at low water are feeble streams when compared with the St. Lawrence, is often much greater, during high water, than that of the St. Lawrence. Hence, so far as concerns the maximum volume of water in cubic feet per second which they carry, there are several rivers, of the magnitude of the St. Lawrence, which have already been dammed and developed for power and navigation, but with the immense comparative disadvantage that their high stages of flow are liable to occur with great suddenness and with little warning, thus giving rise to an ice and flood hazard which can never, under any conceivable circumstances, obtain in the St. Lawrence. It may be stated, therefore, that the improvement of the St. Lawrence river offers no temporary, seasonal or permanent hazards which have not been already encountered in connection with river improvement works constructed elsewhere.

IV. Regulation

The very efficient natural regulation of the St. Lawrence has already been referred to at length in Section II of this report; nevertheless, many important advantages may be secured by imposing a further degree of artificial regulation. Furthermore, canalization of the river, or its improvement by locks and dams, is impossible without artificial control, unless the maximum elevation of lake Ontario under natural conditions is to be exceeded.

As has been stated previously, the extreme range under present conditions, in a period of sixty years, has been from elevations 243.41 to 248.95. In order to make regulation possible at all, the control section at the head of the Galops rapids, which under present conditions governs the discharge of the river, must have its capacity enlarged sufficiently to carry the maximum prescribed discharge under the adopted system of control, for any given lake level, without increasing the slope of the river beyond what would permit a reasonable head to be maintained at the dams.

When the object is power development the usual purpose of storage control and river regulation is to increase the low-water or dependable flow, with a consequent increase in the power which can be made available. Ordinarily some degree of control is also possible at times of high water, but this is usually of minor consequence. Where the river is to be developed for navigation, increase in the minimum flow is also a factor of much importance.

In the case of the St. Lawrence, however, there are other factors, in addition to the maintenance of a high minimum flow, which must be considered in any effective system of regulation. Benefits to navigation, dependable power, power-house and equipment costs and the extent of the channel improvements necessary, are all affected by the discharge of the river at medium and high stages, as well as at times of low water.

Briefly, the results to be attained in the control and regulation of the St. Lawrence may be enumerated as follows:

(1) To increase the minimum flow. This will be of advantage to power in the corresponding increase in dependable power to be developed. It will also greatly benefit navigation by lessening the channel improvements required, decreasing the cost of the locks and appurtenant structures, and maintaining a greater and more uniform depth of water in Montreal harbour and in the ship channel below.

(2) To decrease the maximum flow. This will benefit navigation by restricting the velocities in the river at high-water stages within the required limits. It will also decrease the loss of head or slope in the river, both above and below the power plants, and will thus tend to maintain a constant working head. It will in all cases reduce the necessary installed plant capacity in the power houses, and under certain conditions, actually increase the maximum available power.

(3) To restrict the maximum elevation of the lake level to that existing under natural conditions. This is necessary in order to avoid flood damages.

(4) To raise the present limit of lake level at extreme low water. This will also be of benefit to navigation in the consequent deepening of all the harbours on lake Ontario, and it will further decrease the necessary amount and cost of channel deepening in the river, and the cost of locks and other structures.

It will also benefit power development by increasing the total fall available.

(5) To regulate the outflow so as to maintain the mean elevation of the lake at a higher point than exists under present conditions. This will also be a benefit to navigation by reason of its effect on the mean depth of the harbours on lake Ontario.

It will be of considerable benefit in connection with power development, as any increase in this elevation will add at least twice that amount to the total head available for power.

(6) To maintain a store of water which may be drawn upon as required, for special purposes, as for example, the handling and flushing of ice.

Investigation shows that it is not a difficult matter to develop a system of regulation which will achieve, more or less completely, most of the purposes outlined above. As a matter of fact practically an unlimited number might be devised, according to the limits to be imposed for lake level and discharge, all of which would be more or less effective according to the standpoint from which the matter is viewed. Altogether ten different methods of regulation were investigated, and their effectiveness tested by applying them to an assumed repetition of the conditions of discharge of the St. Lawrence as they have occurred during the past sixty years.

The method finally adopted as fulfilling all of the requirements to the best advantage is based upon the elevations of lake Ontario, the supply entering the lake from the Niagara river, and the local supply from the precipitation upon the local watershed of lake Ontario; and is arranged on the basis of maintaining the discharge throughout each month at a constant rate. The proper discharge for any given month is determined by the elevation of lake Ontario at the beginning of the month, and the discharge of the Niagara river together with the local supply to the lake, during the preceding month. This local supply is a factor of considerable importance, as it frequently amounts to from forty to fifty per cent of the supply from lake Erie. Tested by applying it to the conditions which have obtained during the last sixty years, but allowing for a diversion of 10,000 second feet at Chicago, the following results would have been secured:

(1) An absolute minimum flow of 200,000 second feet at all times.

(2) A minimum of about 206,000 second feet, for ninety-five per cent of the time.

(3) A minimum flow of 210,000 second feet, for ninety per cent of the time.

(4) A minimum flow of 220,000 second feet for over eighty per cent of the time.

(5) A minimum flow of 238,000 second feet for fifty per cent of the time.

(6) An absolute maximum flow of 280,000 second feet as compared with the present maximum of nearly 320,000.

(7) The maintenance of mean lake elevation more than one foot above the present mean; and a minimum lake elevation two feet higher than under present conditions for all but six months of the entire period of sixty years.

(8) An ample margin of storage always available for contingencies and special purposes.

The results as given are those which would be attained by a rigid application of the system, practically without modification. In actual practice,

however, there is no doubt that much improvement could be made by taking cognizance of the records of levels and other relevant conditions in the upper lakes, and on their drainage areas.

The minimum discharges just cited will be correspondingly increased if regulation is subsequently secured for lake Erie and the other lakes above.

Finally, the system has the merit of adapting itself to any future change in the discharge of the Niagara river, whether due to regulation or from any other cause.

V. Market Conditions and Prospects§

For some time past the Hydro-Electric Power Commission of Ontario has been delivering power in the city of Windsor, Ontario, two hundred and forty miles from Niagara Falls, at 110,000 volts. Several public service corporations in the United States are operating under similar conditions, and pressures as high as 150,000 volts are at present in successful operation. Recent developments in insulation and high-tension switch construction indicate that the safe handling of large blocks of power at pressures up to 220,000 volts, and the transmission of the same to distances ranging as high as five hundred miles, are certainties of the immediate future. In the light of these facts, it becomes at once evident that not only all of eastern and central Ontario, but a part of the most highly industrialized portion of the United States becomes a potential market for the power in the international reach of the St. Lawrence river. This fact is graphically illustrated on Plate XIII, where an effort has been made to indicate the magnitude of these market possibilities.

In the matter of the United States markets, it is important to note the ideal condition which exists by reason of the immense terminal loads which would be available and to draw attention to the beneficial effect which these loads would have on the unit transmission costs. In connection with this map it is also interesting to note the extent of the existing facilities for transmitting power throughout the territory under discussion. With the exception of a short space of a few miles, which is already being connected up on the American side, and of the gaps between Brockville and Kingston and between Oshawa and Toronto on the Canadian side, there is a continuous system of transmission lines encircling lake Ontario and connecting with the systems radiating from Niagara Falls, both by the way of the north and south sides of lake Ontario. This means that New York state may be considered as already in electrical connection with the Ontario transmission systems extending from Windsor on the west to Cornwall on the east. Such being the case it is not difficult or unreasonable to conceive this existing transmission

§See NOTE on page 20.

network as a ready means not only of absorbing preliminary portions of the available power of the St. Lawrence river, but as a means, through future extensions and interconnections, of absorbing all of the potentiality of the international reach of the St. Lawrence in conjunction with Niagara, as one great unified co-operative system.

Apart altogether from the great waiting load in the cities south of the international boundary, which alone would justify the development of the international reach of the river, it is an established fact that the enormous expansion of the demand for hydro-electric power during the period of the war has opened the eyes of the world to its possibilities as a basic factor in industrial progress. The huge quantities of electric power used in the manufacture of chemicals, alloys, steel and other war material will undoubtedly lead to a much wider use of electric power in peaceful industry. This condition has unquestionably brought the possibility of developing power on the St. Lawrence river within a measurable distance of realization.

In view of the fact that the industrial areas in the United States tributary to the St. Lawrence River power are much more thickly populated and more highly industrialized than the corresponding area in the province of Ontario, all matters pertaining to the development of the power of the international section of the river must be considered independent of the political boundary line, throughout the initial period of growth, in any event. With the transmission of power feasible for such great distances, international boundaries should not necessarily imply curtailment in the transmission and exchange of power, any more than they constitute an impassable barrier in the case of railways, telephones and telegraph systems. This condition does not imply ownership, but merely an interchange of traffic which mutually benefits commerce between the two countries. Such being the case, it is desirable, and in fact almost essential, that there should be provided, under proper governmental control, facilities for the interchange of St. Lawrence power between the two countries, with one important reservation only, to be made on the part of Canadian interests. South of the international boundary line there exist two primary sources of energy—coal and water power. North of the boundary line and throughout central Canada, water power is the only native source of primary energy available. Therefore, if a condition should at any time exist whereby the territory north of the international boundary were in need of any portion of its share of the international power, which was in use in the United States for the time being, such power should be reclaimable by Canada on proper notice.§

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§The experience of the Hydro-Electric Power Commission of Ontario, especially during the last few years, shows a rapidly increasing market for electrical energy and warrants the conclusion that all the electricity that can be produced from Ontario's equity in international waters will be marketable in Canada as rapidly as it can be made available. Consult footnote §§§ on page 7 and NOTE on page 20.

VI. Power Commercially Available

The discussion under this head is based on the proposition that the water power in the international reach of the St. Lawrence river is not to be exploited primarily for personal profit but as an international asset which is to be developed and used in such a manner as to assure the greatest economic benefit to the people of both countries.

In appraising the value of an ordinary water power, the predominant, and in many cases, the only significant factor, is its minimum dependable capacity, the secondary capacity available from intermittent high stages of flow being disregarded, as the short periods of time over which the higher stages of flow ordinarily obtain do not justify the installation cost which would be necessary to make use of them.

The St. Lawrence river is almost unique in that its regulated regimen will be so uniform as to be capable of producing a quantity of continuous primary power which is over seventy per cent of its maximum stage capacity. It has another unique characteristic, furthermore, which merits serious consideration. Its higher stages of flow do not obtain merely over a period of a few days, weeks or months, as in the case of an ordinary river, but actually obtain at times over a period of successive years, and the volume of this high-stage flow is in itself of such magnitude that the secondary capacity obtainable from it cannot be ignored in appraising the value of the river as a source of power, and in laying out a properly comprehensive scheme of development.

Under a certain scheme of regulation which has been devised, and mentioned elsewhere in more detail, it will be possible to keep the St. Lawrence river within limits of discharge ranging from a minimum of 200,000 to a maximum of 280,000 cubic feet per second. The records of the past sixty years show that under this system of regulation there was no period in any year when the discharge would have been less than 200,000 cubic feet per second, and that in the total period of sixty years a discharge of 250,000 second feet or more would have been available for eighteen years; 238,000 second feet for thirty years; 230,000 second feet for thirty-eight years, and 220,000 second feet for forty-eight years.

Under any scheme of development of the international reach of the river which may be finally decided upon, a total net head of approximately eighty-two feet will be available, which under minimum regulated flow conditions would produce 1,700,000 horsepower of primary continuous power.§ The increments of secondary power available on the basis of the figures above cited amount in the aggregate to over 10,000,000 horsepower-years, all of which energy would be available for periods ranging from eighteen to forty-eight years out of the total sixty-year period embraced by the basic records.

Considering the above figures in the light of the proposition set forth at the beginning of this section, it may be stated that a proper degree of ultimate

§Computed with respect to a flow of 210,000 c. f. s.; compare page 65.

conservation in the use of the water of the St. Lawrence river for power purposes must embrace the development and use of this secondary power, and in view of the long periods of time over which these increments of secondary power are available, there is no doubt but that the extensive and diversified market created through the use of the primary power will have sufficient absorptive capacity to make effective use of it.

Throughout New York state, Pennsylvania, and New England there are already in existence large steam central stations having an installed power capacity in the aggregate three times as much as is available in the international reach of the St. Lawrence river. If St. Lawrence power were available to these systems, at a price which could compete with fuel generated power, an immediate market for secondary power would be opened up, and a conservation measure of international significance would come into being. Based on past records, the absorption of this secondary power alone by steam central stations would in sixty years' time obviate the consumption of eighty million tons of coal, which, under present conditions, is being consumed to produce an equivalent amount of steam power. Applying a fair reduction factor to the primary power capacity of the international reach of the St. Lawrence river, it is fair to assume that this quantity of power will permit of about thirteen and one-half million tons of coal per annum to be saved or diverted to other uses. This, together with the estimated fuel saving arising out of the use of secondary power will make a grand total of about fifteen million tons of coal per annum as the fuel equivalent of a properly conceived development of the international water power in the St. Lawrence river.§

VII. Alternative Schemes of Development

During the period in which the engineers of the Hydro-Electric Power Commission of Ontario have been investigating this project, studies were made of various schemes for the development of the international section of the St. Lawrence river for power and navigation. These studies finally resolved themselves into the consideration of three definite schemes, any one of which is physically and economically feasible.

In considering these various schemes, it has not been thought necessary to look upon the present location of the international boundary as irrevocably fixed. Consequently, if it were found that a distinct advantage was to be gained thereby, from a structural or economic standpoint, it has been assumed that any local change in the present position of the boundary line which might ultimately be found necessary, in order to place each of the power houses within its own domain, could be effected without serious difficulty, as part of the general co-operative scheme.

§In the manuscript as originally submitted, the possible annual coal savings mentioned at this place in the Report were inadvertently stated as the savings which would appertain to the whole river instead of to only the international reach. The proper quantities are here presented.

The section of the river located between the province of Ontario and the state of New York, from the head of the Galops rapids to the foot of the Long Sault, has a fall of about ninety-two feet. The general topographical features along this stretch of the river, and the profile of the water surface, indicate two or three well defined situations at which power dams may be more or less advantageously located. Such locations exist at the foot of the rapide Plat, and at the foot of the Long Sault. Three plans of development are presented herewith, and for facility of reference they have been designated as Scheme "A," Scheme "B," and Scheme "C." Scheme "A" is a single-head concentration, while Schemes "B" and "C" are two-stage concentrations.

In most respects, Scheme "A," the single-stage development (See Plates II, III and IV), is similar to that recommended in the report of the engineers to the International Joint Commission. It involves the widening and deepening of the river channels north and south of Galops, Lotus, and Lalone islands, and similar improvements at Sparrowhawk, Iroquois, Rockway and Point Three Points, all of which secure suitable depths and velocities and, at the same time, provide for enlargement of the control section at the Galops, which is necessary to permit artificial regulation of the flow of the river. It also includes control dams in the rapide Plat, and south of Ogden island, and in connection therewith a navigation lock on the American side. There are also to be dams at the head of the South Sault channel, and from Long Sault island to Barnhart island, to maintain the proposed pool level, with power houses at the east end of Barnhart island to utilize the power head thus created. A navigation canal extends from the head of Sheek island to Cornwall, with locks at Moulinette and at its point of junction with the river below. Further river improvements provide the required navigation depths and velocities east of Cornwall. Above the control dam at Ogden island the normal water level will be between elevations 241 and 242, rising to elevation 245 at the head of the Galops island. Earth embankments are required at certain places on the American shore south of Cat island, and on the Canadian shore from a point opposite the head of Long Sault island to the head of Sheek island. A heavy concrete retaining wall backed by an earth fill connects the north end of the Barnhart Island power house with the east end of Sheek island.

The normal operating head at the proposed power house is 74.5 feet.

In connection with the dam at the head of the South Sault channel there will be a power house to utilize, under a head of about twenty-eight feet, that part of the flow of the river diverted to the power plant at Massena, N.Y.

Scheme "B" is identical with Scheme "A" from Prescott to below Point Three Points. From Leishman Point downstream they differ considerably. Just upstream from Morrisburg a dam is to be built in the main river channel which will raise the water to about elevation 241. Two power houses will be built, extending from the east end of Ogden island to Clark island and thence to Murphy Point, which will utilize the head of twenty-

seven feet created by the proposed Morrisburg dam. Provision for the supply of water to the power houses is made by a channel across Ogden island, and by the enlargement of the channel south of Ogden island at Leishman Point and at Waddington. For disposal of ice and flood flows in the river a channel, controlled by a sluice dam, is provided across Murphy Point. Extensive channel improvements will be made between Morrisburg and Weaver Point, to obtain the required navigation depths and velocities.

In this scheme it will be observed that comparatively little flooding of lands is occasioned down stream from Morrisburg.

The locations of the dams at each end of Long Sault island, are the same as in Scheme "A," and the power-house locations on Barnhart island are substantially the same. The head to be developed at these power houses, however, is 54.5 feet, instead of 74.5 feet as in Scheme "A."

The course of navigation follows the present Cornwall canal, which will be deepened, widened, and straightened from Dickinson Landing to the east end of Sheek island, and an excavated canal will be provided from this point to Cornwall, with locks north-east of Maple Grove, and at Cornwall.§

Channel improvements in the river below Cornwall are the same as in Scheme "A."

Scheme "C" is also a two-stage development, the upper dam and power house being placed at Crysler island instead of at Morrisburg, and the lower power houses at Barnhart island. This scheme is identical with Scheme "A" as far down as Point Three Points. From there to Crysler island no works of importance will be required on account of flooding, except the raising of the ground level and the buildings at Morrisburg. A dam will be built from the American shore to Strawberry island and thence to Crysler island, and the power house will extend diagonally across the international channel to the Canadian shore. This dam and power house will create and utilize a head of between twenty-eight and twenty-nine feet.

Navigation will follow the main river channel, which will require no improvement from Point Three Points to Crysler island. Here a short canal with one lock is provided, the navigation channel again entering the river just below Weaver Point. Below Crysler island, Schemes "B" and "C" are identical in every respect.

The descriptions of the different schemes of development, as set forth in the succeeding paragraphs, are intended to give a general idea of the main features of each, without attempting to treat with details in any way. For instance, the general layout of the power houses, dams, and sluices, in relation to each other and to the forebay and tailrace, are necessarily more or less tentative, and the actual location of the different structures must not be considered as definitely fixed or unalterable.

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§Consult inset plan on plate VII. See note on next page.

Before construction of any of these works would be undertaken, more detailed borings and examinations of the sites proposed would require to be made, which might disclose more favourable conditions than anticipated at present. Even after the location of all the structures is definitely fixed, many studies involving alterations and re-arrangements will be made before working plans are finally prepared.

As a matter of fact, alternative methods will continually suggest themselves, in connection with certain features of the schemes, which would bring about considerable improvement, if assurance could be had as to the existence of certain foundation and other conditions.

While such alternative propositions have not been so far referred to in this report, care has been taken to include in all the estimates of cost, for these particular parts of the work, an allowance sufficient to provide for the same, if further information should demonstrate the desirability of so doing.

For example, in connection with Scheme "B," an alternative route to that shown on Plate VII for entrance to the pool north of Sheek island has been studied. Instead of utilizing the present canal location from Lock No. 21 to the Sheek Island dam, it is proposed to take out the entire present canal and embankment, and to further enlarge the adjacent channel, so that navigation may follow the main river down as far as the head of Sheek island. At that point the present Sheek Island dam will be removed and the channel at the same point further enlarged to a width of 800 feet, through which navigation would enter the pool to the north of Sheek island. The corewall embankment shown on Plate VII at the point where the present Mille Roches dam is situated will not then be necessary, and a second channel leading to the forebay will be provided paralleling the channel shown between Barnhart and Sheek islands. The result would be to benefit both navigation and power.§

Another instance where improvement can probably be made, by altering the locations of the power houses and sluice dams shown on the plans, is in connection with the development at the foot of Barnhart island. Further information as to the depths to bedrock will probably indicate that the layout can be considerably improved with regard to the protection of the power houses from running ice, and the handling and sluicing of the ice itself.

In any case, as stated above, the estimates of cost are ample to provide for these alterations if the conditions are found to be such as would otherwise justify the change.

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§When this report was submitted, this reference in the text was made to "an alternative route," for navigation between Dickinson Landing and Bergen lake or the pool north of Sheek island; but, at that time, there was no opportunity to present any drawing on the various plates which had already been completed. There has since been added as an inset on Plate VII, and to half the scale of the original Plate, a sketch showing this alternative route.

SCHEME "A"

Single-Stage Development of Power at Barnhart Island

In the main, the proposed development referred to as Scheme "A," is essentially that recommended to the International Joint Commission by the Government engineers, and is described in the section of their report dealing with Division 4. The navigation features of this scheme are not here described at length because they do not differ from those proposed by the Government engineers, although a few slight changes have been made in the alignment of the channel in order to reduce the amount of excavation when it appeared that a channel equally satisfactory might be secured, at less cost. (See Plates II, III and IV.)

Navigation

All locks are constructed to provide for a draft of 30 feet. Between Chimney Point and Leishman Point, navigation will follow the river channel. The cross-sectional area is increased where necessary and the alignment of the channel improved. In order to avoid raising the level of lake Ontario, rather extensive improvements will be required between the head of Galops island and the foot of Lotus island. It is proposed to remove the Gut dam and enlarge the channel north of Galops, Lalone and Lotus islands. This will permit the closing§ of the south channel without materially affecting the levels of lake Ontario, and the excavation in that channel, south of Galops island, may then be taken out in the dry.

The navigation channel will be on the south side of Butternut, Galops, Lalone, and Lotus islands. It will be excavated to a width of six hundred feet, with the grade at the upper end at elevation 211, and at the lower end at elevation 210. In order to equalize the flow between the north and south channels a cross-over channel will be cut between Baycraft and Lalone island. At mean stage the channels north and south of Galops island will have a minimum combined cross-sectional area of at least sixty-seven thousand square feet.

By excavating at Sparrowhawk Point, Toussaint island, Iroquois Point, Rockway Point and Point Three Points, it is proposed to further improve the alignment of the river and increase the cross-sectional area to at least seventy thousand square feet, which will result in the velocities for mean flow being reduced to an average of 3.5 feet per second. From Point Three Points to below Clark island the navigation channel will be south of Ogden island. A cut will be made through Leishman Point, and the Little river will be deepened to elevation 210 above the old Waddington dam of the New York and Ontario Power Company. The navigation lock (No. 9) will

§That is to say, temporarily, during construction.

be placed just below the old dam, with the upper sill at elevation 208.5 and the lower sill of the lock at elevation 200.5. Two pairs of upper and lower service gates will be provided, also a swing dam above the lock, and at the lower end a pair of unwatering gates. A channel below the lock and through Clark island will be excavated to elevation 205.5. Between Clark island and the Long Sault dam no channel improvements will be required, but as an aid to navigation, sailing banks will be thrown up at certain points.

At the head of Sheek island the course of navigation will enter a canal. One half mile below the entrance, a guard lock having a clear opening of ninety feet will be placed and the present channel will be closed by a retaining wall and sluiceway having six 16 ft. by 18 ft. gates. These structures will be connected to the main shore and to the high ground on Sheek island by corewall embankments. Below the guard lock there will be a lake-like expanse one mile long, at the lower end of which Lock No. 8 will be placed.

Lock No. 8, providing for a lift of 31 ft. will be located opposite the village of Moulinette on the north shore of Sheek island. The coping level will be at elevation 240, the upper sill at elevation 200 and the lower sill at elevation 170. An emergency gate will be placed above the lock, and one pair of upper, and two pairs of lower, service gates will be provided, together with a pair of unwatering gates at the lower end. Between the lock and the mainland, a corewall embankment and concrete retaining wall will be built. Two 10 ft. by 10 ft. sluices will be placed in this dam to by-pass water for the lock and pond below Lock No. 8. These will also permit the unwatering of the pond above.

The canal between Lock No. 7 and Lock No. 8 is about six miles in length. Below Lock No. 8 it passes through the pool formed by the earth embankment extending from the north end of the power house to Sheek island. The water in this pool will stand at elevation 200. Just north of the power house the navigation channel enters a canal about fifteen thousand feet long, which leads to Lock No. 7. The canal prism will have a bottom width of two hundred and twenty feet at elevation 175 and side slopes of 2 to 1.

Lock No. 7 will be located about one thousand feet from the present shore line and to the north-east of the present Lock No. 18. It will have a lift of forty-four to forty-eight feet. The upper sill will be placed at elevation 170 and the lower sill at elevation 122. Two pairs of upper and one pair of lower service gates will be provided, also a pair of unwatering gates. The proposed lock is so situated that it may be constructed without interfering with the use of the present canal. The lower entrance to the lock will connect with the proposed dredged channel between Cornwall island and the Canadian shore.

Power Development at Long Sault

The proposed power plant will be placed at the foot of Barnhart island as indicated on Plate IV. Two power houses will be provided, one to house the Canadian portion of the development and the other the American portion. The Canadian power house is shown as being entirely within United States territory, and is so located in order to provide room for the tailrace without excessive excavation. The site chosen appears to be the one best fitted for economical development.§ To provide for the handling of floating ice, the power houses will be placed at a more acute angle with the general direction of the channel than shown. For the same purpose a sluice ten feet deep and ninety feet wide will be provided at the north end of the Canadian power house. Six similar sluices will be placed between the two power houses, space for which will be secured by the change in location just mentioned, and another single sluice at the south end of the American power house.

The two power houses are designed to accommodate fifty-two units, and will have a combined length of 3,380 feet. The units will be vertical type, single-runner turbines, direct connected to generators of 31,000-kv-a. capacity, delivering 3-phase, 60-cycle current at 12,000 volts, and having individual direct-connected exciters. Each unit will deliver 34,180 electrical horsepower to the low-tension bus when operating at a head of 74.5 feet, providing for a total installed capacity of 1,777,360 electrical horsepower, or a grand total for Scheme "A" of 1,861,840 electrical horsepower, including the auxiliary development in the South Sault, as described hereunder.

The power houses have been so designed as to permit the proposed working level of 231 to be increased to elevation 240, in order ultimately to make use of all the available power.

Retaining Walls and Embankments

A concrete retaining wall backed by an earth fill, will extend from the end of the ice sluice at the north end of the Canadian power house to contour 220 on Sheek island, and thence a corewall embankment will be carried to the 243 contour at the centre of Sheek island. From the south end of the American power house, a corewall embankment will be carried in a westerly and north-westerly direction to the 243 contour near the centre of Barnhart island. Other embankments are provided at different points on the main shore at the upper end of Sheek and Barnhart islands and on Long Sault island. These are necessary to retain the water above the main dam at the working levels, and are indicated on Plate IV. All earth embankments will have side slopes of 3 to 1, and, at an elevation of 243, a top width of forty feet. Where the natural ground surface is above elevation 232 no corewalls are provided. For

§Since this report was submitted, further studies of possible power-house situations have been made and these studies indicate that it is feasible to locate the Canadian power houses entirely on the Canadian side of the present boundary line.

a ground surface elevation of from 232 to 220, a corewall will be placed with a top width of two feet at elevation 238, a width of four feet at the ground line, and six feet below that elevation. These corewalls are carried below the surface a distance equal to their height above the natural ground surface. Where the ground surface is below elevation 220, the corewalls have a top width of two feet at elevation 238, and are carried to rock at a batter of one to twelve. Rip-rap protection is provided on the water side of all embankments.

Main Dam, Long Sault

The proposed main dam is situated at the head of Barnhart island and extends across the main river a distance of 3,750 feet to the lower end of Long Sault island. As designed, it will safely permit of the pool level being raised to elevation 246.

The proposed dam will be in three sections, the two outer ones being provided with sluices. At the east end the section will have ten Stoney gates 15 ft. x 50 ft., with sills at elevation 220 and the west end will have fifteen Stoney gates 11 ft. x 32 ft., with sills at elevation 220. The central section of 2,500 feet will be a spillway with a crest at elevation 231, and the retaining walls and abutments at each end will have a coping elevation of 238.

Ice Diversion Works

Ice diversion works, consisting of six large concrete-capped cribs and a boom, will be built to reach from the east end of the Long Sault dam to Sheek island, as shown on Plate IV. These works are so designed as to divert, when desirable, floating ice to the sluices at the east end of the dam through which it will be flushed to the pool below. Any ice either passing the diverter or formed below it, will be handled by the ice sluices situated at the power houses.

Diversion Cut through Long Sault Island

With a view to reducing the amount of water to be handled during the construction of the main dam, part of the flow of the St. Lawrence will be diverted into the South Sault by means of a cut made through the narrow part of Long Sault island, and a sluiceway will be built in the cut towards its lower end. The width of this cut above the dam will be two hundred and fifty feet, but will be increased to three hundred and fifty feet below the dam, and its grade will be at elevation 165. During the construction of the main dam the sluiceway will remain open, but after construction is finished it will be closed by six gates 11 ft. x 32 ft. having sills at elevation 220.

Dam and Power House at Head of South Sault

At the head of the South Sault another dam is required to complete the channel closure and retain the water at elevation 231. The exact situation of this proposed structure is not fixed owing to lack of data relating to elevations of rock foundations. It is proposed to build here a dam and power

house, the latter to utilize the water diverted at this point for the plant at Massena, N.Y. This dam will consist of spill and sluiceway sections, the spillway to be two hundred feet long, and the sluices to comprise four 50-foot and six 32-foot gates with sills at elevation 220. The power house will be five hundred and twenty-eight feet long with accommodation for eight units, each capable, under a head of twenty-eight feet, of developing 10,560 electrical horsepower, and yielding a total output of 84,480 electrical horsepower.

Control Dam at Morrisburg

An operating level of 231 at the proposed Barnhart Island plant, demands that means be provided for holding lake Ontario at its various regulated levels. Such means may consist of a dam placed either at the head of the Galops rapids, or at some point further down stream, and in either case a lock will be required. It has been decided to place the dam just above Morrisburg rather than at the upper possible site, because the extent of necessary channel improvements may be thereby reduced. The proposed control dam will be 2,400 feet in length and will cross the main channel between Ogden island and the Canadian shore about 2,500 feet down stream from present lock No. 24. At this site the ledge rock forms the bottom of the channel. As designed, the dam is divided into four sections. At the north end there is a retaining wall section 150 feet long, and south of this is a section containing twenty-six submerged sluices each 16 x 21 feet. The third or central section is a six-hundred-foot spillway with crest elevation at 234, while south of this and adjoining Ogden island, is a one-thousand-foot section provided with twenty Stoney sluices, having gates 21 ft. x 40 ft. with sills at elevation 222. The dam is designed to withstand the full static pressure due to a pool level on the upstream side equal to the level of lake Ontario, with the water below the dam down to present levels. Sluices and spillways will pass the maximum flow with a fall through the dam of 2.1 feet. The proposed cut, with sluiceways, through Ogden island, and the dam in Little river, together with the navigation channel and lock, are the same as have been proposed in the Engineer's report to the International Joint Commission.

Flooding

In Scheme "A," the land lying west of the Morrisburg control dam, and below the 248 contour, has been considered as either submerged, or subject to intermittent flooding. Below the control dam the upper limit of the affected area is the 238 contour. The total area involved both above and below the dam amounts to 11,160 acres. In view of the possibility of the operating headwater at Barnhart island being raised at some future time to elevation 238 or 240, it is considered necessary to include in the estimates of flooding all the lands that will be affected by this higher level. The upper limit of the affected area below the control dam will then be the 248 contour also. The total area affected by flooding thus becomes 29,490 acres.

SCHEME "B"

Two-stage Development of Power at Morrisburg and Barnhart Island

The essential difference between Scheme "A" and Scheme "B" is that at Morrisburg the dam will be a combined control and power dam, and will require a much lower pool level at Barnhart island. The pool above the proposed power and control dam at Morrisburg will be maintained at the same level as under Scheme "A," but additional channel improvements will of necessity be required between the upper and lower developments. (See Plates V, VI and VII.)

Navigation

Between Chimney Point and Point Three Points no change in navigation arrangements is necessary but near present Lock No. 24 there is an alteration of the channel location and also of the position of the lock. From Point Three Points the ship channel follows the centre of the main river down to a point opposite Portage bay on Ogden island, where it enters a short canal§ passing through the point of land upon which Mariatown is situated. At this point Lock No. 9 will be located.

Lock No. 9 at Morrisburg

Lock No. 9 is designed for a lift of 28 feet with lower sills at elevation 183 and upper sills at elevation 208.5. The coping will be at elevation 250. Four pairs of service gates will be provided, two upper and two lower, with a pair of unwatering gates at the lower end. Above the lock there will be placed a swing bridge and an emergency gate. This bridge will provide access to the power house for a railway spur, and, by way of the main dam, a causeway at the rear of the power house will provide pedestrian and vehicular traffic facilities between Canada and the United States.

Channel Improvements

Improvements will be required in the channel from Morrisburg to below Weaver Point. The greater part of this work will be north of Doran island and Gooseneck island, and below Crysler island. (See Plate VI.) From this point to the head of Farran Point canal no improvements will be necessary. Between the head and foot of this canal the alignment of the ship channel will not be changed from that of Scheme "A," but the cross section of the channel will be increased by removing the canal bank and by making a cut along the north side of Croil island. This enlargement, at mean discharge and with the proposed pool elevation of 210 at Barnhart island, will reduce the velocity to four feet per second.

§The term *canal*, as here applied to the waterway leading to Lock No. 9, in both schemes B and C could, more correctly, be replaced by the expression *lock approach*.

The ship channel between Dickinson Landing and the pool at Moulinette will follow the old canal to the head of Sheek island. Lock No. 21 will be removed, and the alignment will be improved and the canal widened, by excavating along the north bank and along part of the south bank.§

Between Mille Roches and the Paper Mill, or Lock No. 7, the location of the canal will follow a tangent roughly paralleling the Grand Trunk Railway, keeping behind the high ground between the railway and the river, and on a one-degree curve will join the tangent extending from Lock No. 7.

Lock No. 8

A guard lock above Lock No. 8, with a 90-foot clear opening and a feeder sluice, will be placed about three thousand feet below Mille Roches. Lock No. 8 will be situated twenty-five hundred feet north of Maple Grove, and will provide for a lift of 10 to 11 feet to take care of the difference between the level above Lock No. 7 and the pool level above the main dam. The lower sill will be placed at elevation 170 and the upper sill at elevation 180. The lock will be provided with one upper service gate, two lower service gates, and a pair of unwatering gates at the lower end, the coping elevation being 218. Above Lock No. 8, the grade of the canal will be at elevation 185, and below, it will be at elevation 175, the bottom width being 220 feet.

From the point where the new alignment of the canal meets that provided for in Scheme "A," no change is made in any of the proposed works. A feeder to the reach above Lock No. 7 is provided by means of a weir, or sluiceway, through the embankment across the old canal at Lock No. 20. The level below this point will be held at elevation 200 by means of an embankment across the old canal three thousand feet above Lock No. 19. This embankment will carry the railway spur to the power house and will be provided with valve-controlled conduits to supply water to the mill above Lock No. 18. In Scheme "B" the pond area above Lock No. 7 will be somewhat larger than in Scheme "A."

Power Development Barnhart Island

In this development it is proposed to maintain a constant forebay level of 210. The layout differs in some respects from that shown on Plate IV for Scheme "A." For example, the positions of the power houses are changed so as to form a fairly acute angle with the direction of flow, the outer ends of the power houses being moved farther upstream. Eight 10 ft. by 90 ft. ice sluices are placed between the two buildings, and in addition, one 10 ft. by 50 ft. sluice will be placed at the outer end of each power house. The power stations, housing the full development for both countries, are designed to accommodate in all 50 units and will have a total length of 3,100 feet. These units will be of the vertical type, with generators directly connected to single-

§Consult inset plan on plate VII. See note on page 72.

runner turbines operating at a normal head of 54.5 feet. The generators are each 22,500-kv-a. capacity delivering 3-phase, 60-cycle current at 12,000 volts and have individual direct-connected exciters. Each unit§ will deliver to the low-tension bus 25,000 electrical horsepower, providing for a total installed capacity of 1,250,000 electrical horsepower. (See Plate IX.)

Embankments

To the north of the Canadian power house the river channel will be filled to elevation 223, this fill extending over to the old canal at Lock No. 20, and downstream to a point opposite the crossing of the transmission line to Massena. A corewall carried to rock will be placed near the upstrean face of the fill. A sluiceway having three 10 ft. x 10 ft. sluices will be placed on the site of Lock No. 20, while north of that a corewall embankment will extend to the 223-foot contour. Just north of Maple Grove, a second corewall embankment will fill the draw to the south of the canal. A third embankment§§ of heavy section will extend from the high ground south of the entrance below Mille Roches and across the old canal above the drawbridge to the high ground at the east end of Sheek island. This embankment will be formed by spoiling the material from the canal excavation, and on each side of it the water will stand at practically the same elevation. All these embankments will have a top elevation of 223.

Below the fill to the north of the Canadian power house another heavy embankment will be extended downstream to a point three thousand feet above Lock No. 19, which will serve the double purpose of retaining the water level for the pond below Lock No. 8 at elevation 200, and carrying the railway spur to the power house. A short retaining wall will extend from the south end of the fifty-foot sluice at the outer end of the American power house to the high ground on Barnhart island.

The alignment and cross section of the Sheek-Barnhart channel will be improved by excavating to a minimum width of nine hundred feet, and to a grade of elevation 165. The whole forebay will be excavated to elevation 190 to provide for a maximum velocity not exceeding 3.5 feet per second. Below the power house, the tail race will be taken out to elevation 135, and it is also proposed to cut down Crab Island shoal to elevation 137.

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§When this report was presented to the International Joint Commission, the use of propeller-type turbines was questioned because at that time their development was largely in the experimental stage. Since that time, however, various turbine manufacturers have designed and built large-sized units of the propeller type and such are now being successfully operated. The Commission's engineers, therefore, now propose the use of propeller-type turbines in the St. Lawrence River developments, but contemplate installing larger units, those, for example, for the proposed Morrisburg plant, being 20,000 horsepower each. This will not only effect considerable saving in electrical equipment, but will permit of a considerable reduction in the dimensions of the power house, with consequent saving in cost over the former estimates.

§§This third embankment will not be required under the alternative proposals shown on the inset plan of plate VII, as referred to on page 72.

Structures in Vicinity of Long Sault

It is proposed to place the main dam for the lower development between the head of Barnhart island and the east end of Long Sault island. This site is the same as that for Scheme "A." The total length of the structure will be 3,700 feet, made up of three sections. The easterly and westerly sections will each be 600 feet long, and have twelve sluices provided with Stoney gates 18 feet x 40 feet and sill at elevation 193. The central part of the dam is a free spillway section 2,500 feet long. In addition, there will be between the east end and Barnhart island a retaining-wall section with coping at elevation 222.

Ice diversion works, consisting of a number of rock-filled, concrete-capped cribs and booms, will extend from the east end of the Long Sault dam to Sheek island.

With a view to reducing the amount of water to be handled during the construction of the main dam, part of the flow of the St. Lawrence will be diverted into the South Sault. Another portion of the flow will be by-passed by means of a cut made through the narrow part of Long Sault island opposite the present Lock 21, with a sluiceway near its lower end. The width of this cut above the dam will be 250 feet but will be increased to 350 feet below the dam; and its grade will be at elevation 165. During the construction of the main dam the sluiceways will remain open but after construction is finished they will be closed by seven gates 18 ft. x 40 ft., and the sills raised to elevation 193.

Upper Development—Morrisburg

For the upper development at Morrisburg the two power houses will be placed in line with each other and will be nearly parallel to the general direction of flow. The Canadian power house occupies the channel between the lower end of Ogden island and Clark island, and the American power house will be between the east side of Clark island and Murphy Point. A concrete retaining wall will extend from the west end of the Canadian power house up through Ogden island to a point opposite boundary monument 36, and an embankment will connect this point with the south end of the main dam placed across the channel north of Ogden island.

In the Canadian and United States power houses which will have an over-all length of 4,290 feet it is proposed to install sixty-five units, each developing 10,800 electrical horsepower under a normal head of twenty-seven feet.§ (See Plates VIII and XII.)

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§See footnote on opposite page.

Morrisburg Dam

The dam across the main channel of the river extends from the lower end of Portage bay on Ogden island to the high land east of the bay above Mariatown. Including an earth embankment 300 feet in length, it has a total length of 2,575 feet. There will be 600 feet of free spillway section with crest at about elevation 241, twenty Stoney sluices 21 feet x 40 feet, and sills at elevation 222, also twenty-four submerged sluices 21 ft. x 16 ft. The dam, with the proposed channel improvements completed, will discharge 304,000 c.f.s. with the lake level at 248.5.

As far down as the foot of Murphy island it is proposed to divide the river into two channels by an embankment connecting this island to the power house. The southern channel will be connected to the forebay of the plant by a channel 600 feet wide through Murphy Point. A dam, provided with 350 feet of submerged sluices and 250 feet of ice sluices, will be placed across the upper end of this channel. These sluices will provide ample capacity to take care of any part of the flow in excess of 220,000 cubic feet per second which will be discharged down the north channel.

The channel south of Ogden island, known as Little river, with the channels east and west of Clark island, will form the forebay of the proposed development. There will be three inlets to this basin, of which the present mouth of Little river will form one. This channel will be improved by cutting off part of Leishman Point, by deepening the channel of Little river, and by removing the dam near Waddington. A cut 300 feet wide will also be made across the low part of Ogden island west of Waddington, with a bottom grade of 213. In addition to this channel, there will be another channel across the island just above the main dam. No excavation is contemplated here inasmuch as there will be a maximum depth of water of eighteen feet with a pool level of 240.

The forebay just in front of the power house will be excavated to elevation 190, and the tailrace will be excavated to the same grade.

Flooding

West of Morrisburg, the amount of land damaged due to raising the water under Scheme "B" is the same as under Scheme "A." All land below the 248 contour has been considered as subject to flooding or seepage, even though the ordinary working level at Morrisburg will be 241. Between Morrisburg and the foot of Barnhart island, the area affected will be little more than under present conditions. The total estimated area, which will either be submerged or subject to damage, is 6,345 acres. In this scheme the villages of Morrisburg, Aultsville, Farran Point and Dickinson Landing, will not be damaged.

SCHEME "C"

Two-Stage Development of Power at Crysler Island and Barnhart Island

The third method of proposed development, designated Scheme "C," is also a double development. In every particular the lower development at Barnhart island for Scheme "C" is identical with that for Scheme "B." The provision made for navigation is also identical from the vicinity of Weaver Point to lake St. Francis. Scheme "C," however, differs from Scheme "B," in that the upper power house is placed at Crysler island instead of at Morrisburg.

Under Scheme "C" the upper power house will be placed wholly in the international channel, extending downstream from Crysler island approximately parallel to the line of flow. A corewall embankment and sluiceway by way of Crysler and Strawberry islands will connect the westerly end of the power house with the American shore. From the lower end of the power house, an ice sluiceway and earth embankment will extend to the high ground on the Canadian shore. Navigation will be provided for by a canal and lock behind Weaver Point to overcome the difference in level. (See Plates VII, X and XI.)

Navigation

Under Scheme "C" the provision for navigation will be identical with that in Scheme "B" between Chimney Point and the head of Ogden island, and from below Weaver Point to lake St. Francis. In place of having a canal and lock at Mariatown, however, the ship channel will follow the main stream north of Ogden and Canada islands, joining the alignment of Scheme "B" just above Lock No. 23, and thence following it to the lower end of Gooseneck island. From there the channel will swing slightly north and run on a line nearly parallel with the present north shore, entering a short canal§ across Weaver Point opposite to the lower end of Crysler island. This canal will continue on the same line for 3,600 feet, turning thence to the right on a one-degree curve through a central angle of twenty-six degrees, and then following a tangent for 4,800 feet to join, in midstream below Weaver Point, the alignment proposed for Scheme "B."

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§Consult footnote on page 78.

Lock

A lock of twenty-nine-foot lift will be placed 1,200 feet back from the present shore line at the lower end of the canal. Two pairs of upper and two pairs of lower service gates will be provided; also a pair of unwatering gates at the lower end. The upper sill will be placed at elevation 210, the lower one at elevation 182, and the coping at elevation 248. To provide for the present fourteen-foot navigation during the construction of the power house, and in order to permit at that time of a lower water level above the dam, it is proposed to excavate the canal first. The upper reach will be taken out to a bottom width of 144 feet and to elevation 196. A temporary upper sill will be placed in the lock at this elevation and on completion of the dam and power house this will be raised to elevation 210.

Above the lock a swing bridge and an emergency gate will be built across the canal. The bridge will provide access to the power house for a railway spur and, by means of the causeway at the rear of the power house, will afford pedestrian and vehicular traffic facilities between the Canadian and the United States shores.

Power Development Barnhart Island

In Scheme "C" the lower development will be at the foot of Barnhart island, and as regards location of power house, dams, embankments, elevation of structures, pool levels, and installed capacity, is identical with that proposed for Scheme "B;" consequently, no further reference need be made to this part of the scheme.

Upper Development Crysler Island

The proposal to place the power house across the international channel at an acute angle with the direction of flow is for the primary purpose of securing a sweeping current across the face of the power house, in order to lessen the difficulty of handling floating ice. The layout shows the power house as one building, but if, for administrative, operating, or other reasons, it is considered advisable to separate the Canadian and United States plants, they may be divided by placing one or more ice sluiceways between the two plants, and reducing by a like number the sluiceways provided at the north end.

The tailrace down to Weaver Point will be excavated to a grade of 185, in order to give additional cross-sectional area in this reach, and the forebay will be excavated to a grade of 190. It will be seen from Plate XI that part of Crysler island must be cut away to make room for the power house.

The power house building will have a total length of 4,224 feet, and is designed to house sixty-four units. Under the normal head of 28 feet each unit will develop 11,400 electrical horsepower.

Dams and Embankments

South of the canal, it is proposed to place a fill with a top elevation of 248. Between this fill and the east end of the power house there will be placed eight ice sluiceways provided with 10 ft. by 90 ft. gates and having their sills at elevation 231. From the west end of the power house, and in line with it, a corewall embankment will be built across Crysler island. It will have a top width of forty feet, and side slopes of 3 to 1. The top of the corewall will be at elevation 240, and the base will be carried to rock. This embankment will connect with a sluiceway dam built between Crysler and Strawberry islands, having twenty-four openings provided with 20 ft. by 40 ft. Stoney gates. Between Strawberry island and the American shore, a second sluiceway dam will be placed having twenty openings provided with 20 ft. by 40 ft. Stoney gates. During the construction of the power house, canal, lock, etc., the crest of the openings will be at elevation 200, but after these works are completed, the crest will be raised and the gates placed with their sills at elevation 222. A concrete retaining wall across Strawberry island will connect the two dams, and a corewall embankment will extend from the south end of the dam to the high ground on the main shore. Between this point and Cole Creek a series of low earth embankments will be required to connect with the 248 contour. The area between the canal and the Grand Trunk railway will be filled to elevation 248 with the spoil from the canal excavation.

A heavy embankment, following the 230 contour to the upper end of the lock, will be built from the fill north of the power house. This embankment will serve the purpose of carrying the railway spur and will act as a retaining embankment for the pond above the lock.

Flooding

In Scheme "C" the land area subject to flooding is, of course, much greater than in Scheme "B." From the power house at Crysler island to the head of the Galops rapids, the flood line follows the 248 contour, and between the upper and lower plants the flooded area is the same as in Scheme "B." The total area involved as subject to damage is 10,900 acres. As in Scheme "B" the villages of Aultsville, Farran Point, Dickinson Landing, and Louisville Landing, are not affected.

VIII. Estimates of Cost

Scope

The estimates submitted as an appendix to this report cover all costs including engineering, contingencies, and interest during construction, in connection with the improvement of the international reach of the St. Lawrence river for navigation and power, as embraced by the specific alternative scheme of development proposed.

All estimates of land and property damage were based on local investigations made during the course of the field operations, but are necessarily a somewhat uncertain factor in the estimates. It is important to note, however, that any future appreciation in the value of the properties or vested rights involved will most adversely affect the single-stage development and affect Scheme "B," the double-stage development, to a minimum degree.

In these estimates it has been assumed that there will be free and co-operative interchange in labor, material, plant and other items and commodities incidental to the construction and involved or included in the completed work.

Whenever mentioned, the cost of power is based upon the delivery of 12,000-volt electrical power at the generator terminals, and does not include the cost of step-up transformation.

Quantities

For the river improvements and navigation works, substantially the same quantities were used as those upon which the estimates of the Government engineers were based, with the exception that an additional contingency item of approximately ten per cent was added more or less throughout, to provide for necessary revisions which may manifest themselves in the course of the preparation of more detailed plans.

The quantities used in connection with the power-house structures were taken out independently, and were based largely upon the surveys and investigations of the Commission's engineers.

It might be mentioned here that one of the main items of difference in the quantities used by the Government engineers and by the engineers of the Commission, lies in the fact that the Government engineers have provided an embankment 8,500 feet long connecting the northern end of the Barnhart Island power house with Sheek island. The engineers of the Commission have replaced this corewall embankment with a concrete retaining wall of gravity section, backed by a very heavy earth fill.

Unit Prices

For the river improvements and navigation works, the unit prices used for earth and rock excavation, concrete, etc., are substantially the same as those used by the Government engineers, but as in the case of quantities, a liberal contingency margin has been included throughout.

In the case of the power-house structures, the unit prices used were derived independently by comparison with similar work done elsewhere and the unit prices, as a whole, were subjected to close scrutiny in connection with their applicability to the governing physical conditions, and as a result they are believed to assure a considerable margin of safety over and above the ordinary contingency item which has been added in every case to the total cost.

One of the main items of difference between the estimates herewith submitted and the estimates of the Government engineers is that a special price of $18.00 per cubic yard has been figured on for the power-house concrete instead of the general average price of $12.00 per cubic yard used by the Government engineers.

Apportionment of Capital Cost

In the appended estimates submitted, it will be seen that an effort has been made to arrive at a distribution of the total cost of the various proposed schemes, between navigation and power. This phase of the problem does not require to be further enlarged upon as the estimates themselves indicate clearly the basis upon which the apportionment has been arrived at.

Initial Developments

In all of the general schemes of development proposed it has been assumed that the scheme finally adopted will not necessarily be constructed complete in one continuous series of operations, and that in the case of power particularly, certain initial installations will be completed and put in commercial operation by a date which may anticipate, by a considerable period, the final completion of the works as a whole, and the installation of generating plant up to the full potentiality of the site or sites developed.

In the case of Scheme "A," an initial development has been assumed to cover the completion of all improvements for navigation, including the control dam at Morrisburg; but only that portion of the main power house at Barnhart island, north of the ice sluices, and the substructure of the power house in the South Sault, are included. One ice sluice is provided at each end of the main power house, and from the end of the south ice sluice, an earth embankment with a corewall extending to rock and reaching to the 240 contour of Barnhart island, will also be built. This arrangement will accommodate 27 units, providing for a continuous capacity of 735,000 electrical horsepower.

The cost of the initial development above described will be $93,418,018, or $127 per horsepower, as compared with $141,696,192, or $95 per horsepower, for the completed development under Scheme "A."

An initial development for Scheme "B" involves the completion of the navigation scheme from Prescott to Cornwall together with the power houses at Morrisburg. The principal deferred items will be the main Long Sault dam, the power houses on Barnhart island, the ice diverter and ice sluiceways at that point, and the forebay and tailrace excavation. Under this scheme, a temporary rock-fill dam will be required at the head of the Long Sault.

The initial installation will have a continuous capacity of 600,000 electrical horsepower at 27-foot head, and the cost will be $76,410,232, or $127 per horsepower, as compared with a total of $154,092,512 or $96 per horsepower, for the completed work under Scheme "B."

In the case of Scheme "C" an initial development involves the completion of the navigation scheme from Prescott to Cornwall, and the power house and dam at Crysler island. The principal deferred items are the main Long Sault dam, the power house on Barnhart island, the ice diverter and ice sluiceways at that point, and the forebay and tailrace excavation. Under this scheme a temporary rock-fill dam will be required at the head of the Long Sault.

The initial installation at Crysler island will have a continuous capacity of 635,000 electrical horsepower, and the cost of the same will be $78,504,100, or $124 per hosepower, as compared with a total of $154,925,415, or $95 per horsepower for the completed Scheme "C."

In the above described proposals for initial development, the assumption has been made throughout that complete river improvements for deep-draft navigation would be an integral part of any initial development scheme which might be adopted. With respect to this phase of the problem, however, it is desirable to consider another possible solution, namely, an initial development primarily for power purposes, and with navigation considered only in so far as concerns the necessity of designing and locating the power-development works so as to provide for the harmonious and economical improvement of the river for deep-draft navigation at a later date.

In the case of Scheme "A," an initial development under this head involves the omission of all river improvements, and no navigation works except the raising of the embankment and lock walls at Lock No. 21 to safely provide for the maintenance of fourteen-foot navigation only. The dam at Barnhart island would be built with its full ultimate width of section, but only high enough to accommodate a head-water level of elevation 210, thus providing a working head of 48 feet. The power house would be built and turbines installed for the full ultimate head, and making allowance for the reduction in efficiency and capacity due to the lower initial head, the continuous output of this plant would be about 585,000 electrical horsepower.

The cost of the initial development above described would be $135,980,760, or $232 per horsepower, as compared with $141,696,192, or $95 per horsepower, for the completed Scheme "A."

In the case of Scheme "B," an initial project would provide for the maintenance of fourteen-foot navigation throughout, with only sufficient improvement through the Galops rapids to permit the necessary raising of the water level at Morrisburg without affecting the regulated level of lake Ontario. The power houses and installation at Morrisburg would be completed for full capacity working under a twenty-seven-foot head with a resultant continuous capacity of 600,000 electrical horsepower.

The cost of this project would be $75,223,785, or $125 per horsepower, as compared with a total of $154,092,512, or $96 per horsepower, for the completed Scheme "B."

In the case of Scheme "C," an initial project would be similar o that above proposed for Scheme "B," the only difference being that the power houses would be located at Crysler island instead of at Morrisburg, thus providing a head of 29 feet and a continuous capacity of 635,000 electrical horsepower.

The cost of this project would be $79,980,826, or $126 per horsepower, as compared with a total of $154,925,415, or $95 per horsepower, for the completed Scheme "C."

Summary of Capacities and Costs:

For convenience, there has been assembled hereunder a summary of the figures set forth above, and in detail in the appended tables of estimates. These figures have reference to power development only, and are based upon the assumed apportionment of total costs above mentioned.

SUMMARY OF CAPACITIES AND COSTS

Item	Continuous capacity	Total cost	Capital cost per horsepower
Scheme "A" complete	1,492,000	$141,696,192	$95
Scheme "B" complete	1,600,000	154,092,512	96
Scheme "C" complete	1,635,000	154,925,415	95
Initial Scheme "A" with complete navigation improvements	735,000	93,418,018	127
Initial Scheme "B" with complete navigation improvements	600,000	76,410,232	127
Initial Scheme "C" with complete navigation improvements	635,000	78,504,100	124
Initial Scheme "A" with 14 ft. navigation only	585,000	135,980,760	232
Initial Scheme "B" with 14 ft. navigation only	600,000	75,223,785	125
Initial Scheme "C" with 14 ft. navigation only	635,000	79,980,826	126

IX. Comparison of Different Schemes of Development

A discussion of this phase of the problem involves the consideration of the following points: general features; flow control and regulation; ice conditions and operation; construction hazards and duration of construction period; operation; property damage; power capacity; and capital cost.

General Features

The main point of difference between the various methods of development depends upon whether the total development takes place in two stages or in one.

In Scheme "B," which is an example of the former method, the height of the dams and pool levels conforms fairly closely with the natural profile of the surface of the river, the principal increase in height being at the power houses which are located at the foot of the rapids. In other words this method of development is in harmony with the actual physical conditions, and as a consequence, the river is usually confined within its present banks.

Scheme "A," on the other hand, in which the entire fall is developed at one point, necessitates the location of the power house at the foot of Barnhart island below the Long Sault. A reference to the contour lines on Plate IV will show that the natural elevations of the adjacent mainland shores are much too low for this purpose. Fortunately, however, both Barnhart and Sheek islands are considerably higher, and it is only by taking advantage of this circumstance, and by carrying the pool level down between the islands, that a single development becomes practicable, and even this cannot be accomplished without extensive dyking.

In the case of Sheek island, for three-quarters of its length, the required elevation can only be secured in this way. Its lower end, furthermore, is about a mile and a half short of reaching as far down as the lower extremity of Barnhart island, where the power house must be located, so that it must be artificially extended to this point by means of a retaining wall and embankment one hundred feet in height, and over eight thousand feet long.

Barnhart island is somewhat higher, but for about half of its length it must also be raised by embankments on the low contours.

This method of dealing with the situation consists, therefore, in carrying the pool level down the Little river, between Barnhart and Sheek islands, to a forebay at the lower end, and utilizing the present main channel of the river south of Barnhart island as a by-pass for surplus flow during high water, and also under certain conditions, for the flushing of ice.

Flow Control and Regulation

Inasmuch as Scheme "A" includes control works at Morrisburg, there is little to choose between the three schemes under consideration so far as concerns the effective manipulation of the outflow from lake Ontario.

Ice Conditions and Operation

The essential points in connection with this whole question are as follows:

Under present conditions, the only place where serious trouble results from the effects of ice is in the stretch between the head of lake St. Francis and the head of the Long Sault. This is due entirely to jams first forming at the head of the lake, and later at points further upstream and for some distance up the rapids themselves. These jams are caused almost entirely by an accumulation and packing of anchor ice and frazil, occasionally accompanied by slush from drifting snow and fragments of sheet ice. In comparison with the anchor ice and frazil, however, not only as to the total amount produced, but also in regard to its actual effect in producing jams, all other kinds of ice are relatively of little importance.

The frazil, anchor ice, and other forms of ice which cause the jams at Cornwall, originate in the forty-eight mile stretch of river between Prescott and Cornwall, of which about twenty-four miles consist of true rapids. A large proportion of the total amount forms in these rapids, where the conditions are particularly favorable.

In any of the different methods for developing the river, no great difficulty will be experienced in the handling of running ice, either in the river and pools, or at the power plants, if properly laid out and equipped for this purpose. For the most part, this condition will only occur for comparatively brief periods at the beginning and end of the winter.

The only ice difficulties of real importance in connection with the operation of these developments will be the backwater in the tailrace of the Barnhart Island power house, caused by ice jams below, and the reduction in pool level, and possibly in discharge, due to a complete ice cover in the pools, and the accumulation of anchor ice and frazil beneath it.

All of the schemes of improvement proposed involve the drowning out of the rapids, which in itself will eliminate the larger part of the anchor ice and frazil, and on that basis the various schemes will be equally effective. The amount of ice of this kind which will continue to be produced, will depend upon the extent of the area of open water still remaining in the pools above the dams and power houses.

In the beginning of the winter, before the permanent ice cover has formed, there will be a period during which the conditions are particularly favorable to the formation of anchor ice and frazil, and during which such

bordage ice as forms will be frequently broken up and re-broken by winds, changes of level, or thaws. All of the ice formed at this time will flow down the river past all of the power plants, and on this basis of comparison, therefore, there will be little advantage for any one method of development over any other.

For the remainder of the winter, after the solid sheet ice has become permanently established, the production of anchor ice and frazil, as governed by the existence of open water, may be compared on the basis of the following facts:

At the beginning of the winter the total area of water surface between Prescott and the dams and power houses of the Barnhart Island developments will be from 36.7 to 40.4 square miles for Scheme "A" according to the working pool level finally adopted. The corresponding figures for Schemes "B" and "C" will be 31.35 square miles, and 33.6 square miles, respectively. From the downstream side of all the Barnhart Island plants to the foot of St. Regis island, there are about 9.5 square miles of open river surface in which the ice formed at this period will be carried down the river until arrested by the continuous ice cover on lake St. Francis.

From Prescott as far down as Morrisburg the conditions, after the ice is formed, will be identical for all three schemes. The velocity of the current in this stretch will be considerably reduced, especially at Sparrowhawk and Rockway Points, but will still be so great as to prevent the river freezing entirely over, though it is probable that in very severe winters, a cover of packed ice may be induced to form for some distance upstream from the Morrisburg control works. Bordage ice, however, will form in the bays as under present conditions, and probably to a greater extent. In ordinary years, the area thus formed may amount to half of the 17.5 square miles of water surface in this reach.

Under Scheme "A," as proposed, from Morrisburg to Bradford Point, the velocities will average about two feet per second, which in most winters will be sufficient to prevent this reach from freezing over completely. From there to Lock No. 21, with the exception of the channel past Farran Point, the average velocities are in the vicinity of one foot per second and this stretch would, therefore, probably freeze over every winter. For the remainder of the distance to the power house on Barnhart island, the velocities will range from two feet per second, a little below Lock No. 21, to three and a half feet per second in the Barnhart-Sheek Island channel, which condition would prevent the formation of a continuous ice cover.

Under Scheme "B," from Morrisburg to the head of the Long Sault, the natural level is not greatly raised, and navigable velocities are secured in many places only by enlarging the channel, as shown on Plates VI and VII. This is also true of the remainder of the distance to the Barnhart Island power

house. Hence, this portion of the river will remain open, so far as the main channel is concerned, but the bordage ice would cover a considerably larger area than at present.

Under Scheme "C," from Morrisburg to the plant at Crysler island, the velocities will also be low, and the pool will freeze over. From Crysler island to the lower power house at Barnhart island the conditions will be exactly the same as in Scheme "B."

If we assume that in average seasons the bordage ice will cover sixty per cent of the water surface above Morrisburg, and that in Scheme "A," the open water surface below Morrisburg will be reduced by ninety per cent, in Scheme "C" by eighty per cent, and in Scheme "B" by sixty-five per cent, the total areas of open water exposed under the three schemes will be as follows: "A"—9.2 square miles; "B"—11.8 square miles; and "C"—10.2 square miles. Hence, on this basis, it will be seen that there is very little difference between any one of the three methods of development.

It should further be pointed out in this connection that in this open water there will be very little anchor ice formed as the depth in the main channel will always be thirty feet or over.

It is, however, in connection with the question of the final disposal of the frazil, and such anchor ice as does form in midwinter, that the chief difference lies between the different schemes.

In Scheme "B," in which a continuous open channel throughout the pools will be maintained, assisted if necessary by ice-breaking tugs or otherwise, all of this ice will pass downstream to the river below the Barnhart Island power house, and this quantity will add its proportion, which will not be very great, to that which has already been accumulated at the beginning of the winter; and to that extent will increase the backwater at this point.

In Scheme "A," this ice will largely lodge under an ice cover which will extend from shore to shore, and will further decrease a pool elevation already greatly reduced by this ice cover. It may also reduce the flow as well, to a certain extent, if anything in the nature of a jam should occur.

Scheme "C" will partake of the characteristics of both Schemes "A" and "B," as part of the ice will pass down to the river below, and part will accumulate beneath the ice cover in the pool above Crysler island.

Briefly, the comparison of the various schemes with regard to this midwinter formation of frazil and anchor ice reduces itself to the following considerations, namely, that in Scheme "B" the reduction in pool level will be relatively slight as compared with what will occur under Scheme "A," but on the other hand there will be some increase in the backwater in the tailrace; while under Scheme "A" there will be less backwater in the tailrace

and considerably more lowering of the pool level. Consequently, there will probably not be a very great difference between the schemes with regard to the total reduction in operating head throughout the winter season.

Taking all of the above-mentioned points into consideration and keeping in mind the great variation in conditions in different years, it would appear that there is not very much to choose between the different proposed schemes in regard to winter operation.

Construction Hazards and Duration of Construction Period

In the matter of disposal of excavated material, Scheme "A" has the advantage over both of the other schemes in that the river-improvement work is more concentrated and the quantities to be moved are less.

Schemes "B" and "C" have the advantage over Scheme "A" in that they are not subject to so many uncertain contingencies in the matter of foundations and earth embankments. The numerous high embankments necessary in connection with Scheme "A" constitute a construction hazard, the gravity of which cannot be foreseen or appraised until the work is in progress. The aggregate length of corewall to be founded in trenched rock constitutes also a serious cost contingency in view of the stratified nature of the underlying rock structure, and the unavoidable uncertainty as to its exact location and conformation. Scheme "B" stands first in this regard, as the uncertainties with regard to the site at Morrisburg are comparatively trivial, and the corresponding conditions at the Long Sault are much less in proportion, as compared with Scheme "A," by reason of the lower and lighter structures and the greatly reduced length and height of embankments and corewalls.

The main dam at the Long Sault is located in the very midst of the Long Sault Rapids at its swiftest and deepest point, and the river flows in a narrow and deep channel of unknown depth, in which the only way to determine foundation conditions definitely, before construction, will be by means of a vertical shaft with horizontal borings under the bed of the river.

The cofferdam work will be unusually difficult, and, in fact, the whole unwatering process will be one of the most difficult undertakings of its kind; furthermore, it is absolutely essential to divert a large proportion of the flow of the river before this cofferdam can be put in place. During the winter there will not only be the difficulties arising from running ice, but trouble may also be experienced on the downstream side as well, as in the past the ice pack has extended up to this point and beyond, raising the water at least twenty-five feet above its normal level. This would involve a risk of the cofferdam being over-topped, and the whole work flooded, with resulting serious interruptions and delays. These cofferdams must therefore be of great strength and height, and the cost will be high.

In order to diminish to the greatest extent possible, the risks and difficulties mentioned, it will be absolutely essential to first complete the construction of the control dam at Morrisburg, for the double purpose of controlling the flow of the river and of diminishing the quantity of ice from above, by drowning out the rapide Plat and Galops rapid. The control dam will take at least two years to complete.

The power house and appurtenant works can, of course, proceed from the first; and with the exception of backwater and ice packs from below, may be carried out without any special difficulty.

In the carrying out of Scheme "B," the complete initial installation for power will consist of the dam and power plant at Morrisburg, and will not require any work at the Long Sault in connection with the second stage of power development.

The site selected for the Morrisburg power house, shown on Plate VI below Ogden island, lies in a quiet and shallow portion of the river which carries but a small part of the total flow, and which can be cut off entirely from the main river by an embankment of earth, connecting Ogden island with Clark island and Murphy Point. This, with the shutting off of the present flow down the Little river, which is very small, will permit the whole area inside the earth embankment, in which both the power house and the sluice dam are located, to be easily unwatered.

The cofferdamming of this portion of the work is therefore a very simple matter indeed, and can be carried out without any risk whatever from ice or flooding, and at a very low relative cost.

The power house and adjacent works can be completed in two years, and during the same period, the navigation lock can be completed, almost entirely in the dry, together with the diversion channel across Ogden island, and the enlargement at Leishman Point. The south end of the main dam can also be constructed during this period, and in comparatively quiet and shallow water. The present fourteen-foot navigation can proceed as usual, during the whole period of construction, by way of the Morrisburg canal, with a possible raising, by a few feet, of Lock No. 24, and the canal bank above the site of the main dam. If desired, the present canal can be connected to the new lock at any time after the same is completed.

With the completion of the power house and the other works referred to, the remaining portion of the main dam may be undertaken. A large part of the flow of the river may then be diverted, and protection from running ice, which will be largely broken up in the "Shells," or the first pitch of the rapide Plat, can be secured by constructing the upper cofferdam at such an angle with the direction of flow as to enable it to function as a shear dam.

The rock in the river bottom at the site of the main dam is all exposed, and at a comparatively high elevation, so that the cofferdam construction presents no unusual structural difficulties of any kind.

Under these circumstances, the Morrisburg development of Scheme "B" can be completed and delivering power probably three years in advance of the Barnhart Island development under Scheme "A."

The Barnhart Island development, which constitutes the second installation under Scheme "B," may be undertaken when the power is needed, and without the delay consequent on waiting for the construction of the control works at Morrisburg, which would save two years, at least, in time of completion. The whole of the navigation works in the vicinity of Barnhart island would also have been completed; hence this part of the work, which is of considerably less magnitude and extent than in the high-head scheme, can also be carried out within four years.

In Scheme "C", the initial development at Crysler island, about which there is some uncertainty regarding the foundation conditions, would in any case take a considerably longer time to construct than is required for the Morrisburg development of Scheme "B." The depth to rock is much greater, and the cofferdams would have to be constructed across the main channel of the river, being thus exposed to the full force of the current and the ice. Also owing to the depth of the water, it is evident that the cofferdams required would have to be of a very permanent nature, would take much longer to place, and would cost very much more than similar structures at Morrisburg.

Permanent Hazards

There are no striking comparisons to be made under this head between the different schemes except possibly to point out that the construction hazard mentioned above in connection with the long and high embankments at the Long Sault, under Scheme "A," constitutes also a permanent hazard somewhat greater than would result from the construction of works at the Long Sault as contemplated under Schemes "B" or "C."

This comparison would, of course, be greatly accentuated if the head on the single-stage development at the Long Sault were ever raised to make available the head wasted at Morrisburg under Scheme "A."

Operation

Under this heading, Scheme "A" has the advantage over the other two schemes in that fewer units are required for the development of a given amount of power, which factor tends to a simpler and more compact plant layout. On the other hand, the larger number of individual units necessary under Schemes "B" and "C" tend to greater flexibility and the more economical and efficient production of peak load and secondary power.

In the case of Schemes "B" and "C", two power plants will require to be operated.

In the case of Scheme "A," the control dam will require to be operated in addition to the main power plant at Barnhart island and the power plant at the head of the Long Sault.

Property Damage

The extent of lands required for flowage under the different schemes varies greatly. In Scheme "A" the lands involved amount to 11,160 acres; this area must be increased, however, for the full ultimate development, to 29,490 acres. In Scheme "B" the area affected is 6,345 acres, and in Scheme "C" it is 10,900 acres.

The lands bordering the north shore of the St. Lawrence river between Cornwall and Prescott were, to a large extent, originally settled by United Empire Loyalists. The best lands in this territory, and consequently the most thickly settled, lie close along the shore of the river. They are among the earliest settled lands in the Province, and the homesteads, churches and public institutions have existed and functioned for several generations. It seems evident, therefore, that if any scheme of development on the St. Lawrence river necessitates the injury, destruction or elimination of these interests and institutions, a sentimental factor is introduced which cannot be appraised as a definite cost item, but to which, nevertheless, due respect must be accorded.

Mention has been made above of the extent of land damage which would be involved in the adoption, respectively, of any one of Schemes "A," "B," or "C." Scheme "A" in its preliminary stage will seriously affect the landed interests above mentioned, and the ultimate development of the full head would greatly increase the damage. The advantage under this head lies very clearly and definitely with Scheme "B," and with Scheme "C" next in order.

Apart altogether from injury to farm lands, the adoption of Scheme "A" will involve the flooding of the villages of Aultsville, Farran Point, Dickinson Landing, Louisville Landing, and large portions of the towns of Morrisburg and Iroquois.

With the exception of the town of Iroquois, the flooding of these municipalities would be avoided entirely by the adoption of Scheme "B," while Morrisburg would be the only additional municipality involved in adoption of Scheme "C."

Under Scheme "B," there would be no flooding of consequence below the village of Morrisburg, and under Scheme "C" the damage under this head would only extend as far down as Crysler island, leaving the remaining portion of the lands between these respective points and Cornwall practically unaffected.

It may be also suggested that whatever scheme of development is adopted, all flooding rights, easements, etc., should be acquired for the full ultimate

development at the outset. This is very necessary by reason of the fact that where lands are taken by expropriation or by arbitration, the British law provides that the property in question shall be appraised on the basis of the value to the owner at the time of taking. Such being the case, if the acquisition of essential rights were deferred until an industrial area were built up along the St. Lawrence river through the use of the developed navigation and power, values in the district would appreciate enormously and the resulting costs would ultimately impose a severe burden on the undertaking as a whole.

Power Capacity

The power capacities under the different schemes are set forth in detail in the preceding section entitled "Estimates of Cost," and show that Schemes "B," and "C" have a relative advantage over Scheme "A" to the extent of about 100,000 horsepower.

It should be noted also that all estimates of power capacity include full allowance for the comparative working heads under the various schemes and for all differences in the efficiencies of the various turbine installations.

Capital Cost

An examination of the detailed estimates, together with the summary of costs set forth in the Appendix, appears to justify the following comment:

In order that the several schemes presented may be properly judged on the basis of capital cost, attention must be drawn to the fact that the estimate for the Crysler Island development, under Scheme "C" is not based on as reliable evidence regarding foundations as in the case of the several developments under Scheme "A" and Scheme "B." Consequently the estimates in connection with Scheme "C" have an element of uncertainty and cannot be assigned the same weight.

The total costs set forth in the estimates show Scheme "A" with an apparent advantage over both Schemes "B" and "C." If, however, there is provided power-house equipment of such design and capacity as to admit of it being used ultimately under the maximum head available, an additional $4,000,000 would require to be added to the estimates as now presented in connection with Scheme "A." The extra power available under Schemes "B" and "C" is suceptible of a fair valuation to be credited to these schemes as against Scheme "A." On the basis of $100 per horsepower, this credit would amount to $10,000,000.

Furthermore, the fact that Scheme "B" would be in commercial operation, with 600,000 horsepower initially available, three years before power would be commercially available under Scheme "A," constitutes an advantage of great significance from a standpoint of financing and market development. This factor would be also reflected in the relative capital costs of the two schemes.

Conclusion

Arising out of the above discussion, it seems justifiable to point to one conclusion of peculiar significance—that is, that after taking into consideration all essential factors in connection with the various schemes and giving them due weight from the standpoint of both adequacy and capital cost, the single-stage and double-stage developments stand practically on a par, particularly as regards Schemes "A" and "B." The final choice must rest, therefore, not upon a preponderance of basic conditions one way or the other, but upon the weight, based on fair and sound judgment, which may be assigned to such secondary issues as flooding damage and permanent hazards, time necessary to construct, and from the financial standpoint, the means best suited to putting the project on a revenue-producing basis in the least time.

Special Acknowledgments

The interior arrangements for the electrical equipment of the power houses, the general plans for the power-house superstructures, and the estimates of cost for this portion of the various schemes as submitted, were prepared under the direction of Mr. E. T. J. Brandon, Electrical Engineer of the Hydro-Electric Power Commission.

Throughout the whole course of the investigations, from the inception of the original field surveys to the completion of this report and the final estimates, Mr. T. H. Hogg has collaborated with the undersigned, much of the work being carried through under his immediate direction.

The undersigned wish further to express their appreciation of the energetic and efficient assistance rendered by Messrs. J. J. Traill, M. C. Hendry and B. B. Tucker of the engineering staff of the Hydro-Electric Power Commission, in connection with the carrying out of the surveys and hydraulic studies, and with the preparation of this report.

All of which is respectfully submitted,

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

F. A. Gaby, *Chief Engineer*
H. G. Acres, *Hydraulic Engineer*
R. S. Lea, *Consulting Engineer*

APPENDIX

TABLES OF ESTIMATES

ST. LAWRENCE RIVER DEVELOPMENT

ST. LAWRENCE DEVELOPMENT—Estimate No. 1

November 10, 1921

COMPARATIVE ESTIMATES OF SCHEME "A" SINGLE DEVELOPMENT AT BARNHART ISLAND;
SCHEME "B" DOUBLE DEVELOPMENT AT MORRISBURG AND BARNHART ISLAND; AND
SCHEME "C" DOUBLE DEVELOPMENT AT CRYSLER ISLAND AND BARNHART ISLAND

No.	Item	Scheme "A"	Scheme "B"	Scheme "C"
1	Channel improvements, South Galops	$9,963,400	$9,963,400	$9,963,400
2	Channel improvements, North Galops	3,891,300	3,891,300	3,891,300
3	Unwatering Galops channels	1,255,000	1,255,000	1,255,000
4	Channel improvements, Lotus island to Leishman Point	3,468,100	3,144,910	3,144,910
5	Excavation on and near Ogden island, except for lock and navigation channel	1,721,000	1,175,540	....
6	Lock at Ogden island	3,117,310	....	....
7	Lock at Mariatown	....	3,136,250	....
8	Excavation above and below lock	330,970	2,315,230	....
9	Dam at Ogden island	2,161,800	2,364,230	....
10	Earth embankments at dam	200,860	509,020	....
11	Unwatering dam site	1,200,000	1,100,000	....
12	Dam in Diversion channel, Ogden island	591,000	....	....
13	Dam in Little river, south of Ogden island	458,700	....	....
14	Cut through Murphy Point and dam	....	1,500,230	....
15	Power house opposite Morrisburg	....	46,940,000	....
16	Unwatering power-house site	....	675,000	....
17	Railway bridge, above lock	....	245,000	....
18	Channel improvements for navigation, Clark island to Weaver Point	669,520	4,601,550	150,350
19	Canal and lock at Weaver Point	....	....	6,045,400
20	Railway bridge above lock	....	....	245,000
21	Earth embankments at lock	....	....	274,170
22	Power house at Crysler island	....	....	45,470,000
23	Ice sluiceways	....	....	1,004,240
24	Earth embankments, Crysler island and United States shore	....	....	718,970
25	Main dam sluiceway and bulkhead sections	....	....	3,810,440

26	Unwatering dam site and power-house site	....	....	3,100,000
27	Channel improvements for navigation, Weaver Point to guard lock	200,250	3,022,040	3,022,040
28	Guard gate, retaining wall and weir at head of Sheek island	2,278,670	....	....
29	Lock at Moulinette	4,158,110	....	....
30	Weir north of Lock 8	266,040	....	....
31	Earth embankment, north of Lock 8	339,710	....	....
32	Navigation channel, below Moulinette	3,864,650	....	....
33	Navigation channel, locks and embankments, Sheek island to Paper Mill Lock	....	9,599,520	9,599,520
34	Paper Mill Lock and entrance piers	4,154,740	4,154,740	4,154,740
35	Dam at upper end of Lock 7	459,390	459,390	459,390
36	N.Y.C. bridge and diversion	315,000	315,000	315,000
37	Electric Railway diversion and lift bridge	100,000	100,000	100,000
38	Culvert to supply water to mills	142,000	142,000	142,000
39	Power house at head of South Sault	5,527,140	....	....
40	Works in South Sault	2,710,820	2,202,540	2,202,540
41	Hooples Creek diversion and dam	1,018,910	....	....
42	Diversion channel and dam on Long Sault island	2,513,450	2,187,230	2,187,230
43	Main Long Sault dam	8,997,900	5,385,150	5,385,150
44	Ice diverter, cribs and boom at head of Barnhart island	139,000	109,400	109,400
45	Excavation between Barnhart and Sheek islands	....	2,042,810	2,042,810
46	Retaining wall from north end of power house to Sheek island	10,584,620	....	....
47	Corewall in fill, power house to canal bank	....	654,430	654,430
48	Barnhart Island power house	62,383,200	46,090,000	46,090,000
49	Ice sluiceways between power houses	2,730,400	2,139,970	2,139,970
50	Retaining wall at south end of power house	405,600	....	....
51	Forebay excavation	895,150	1,863,940	1,863,940
52	Tailrace excavation	2,195,870	2,195,870	2,195,870
53	Unwatering power-house site	370,000	370,000	370,000
54	Excavation Crab Island shoal	423,550	423,550	423,550
55	Channel improvements below canal entrance	4,117,000	4,117,000	4,117,000
56	Land damages	12,460,000	5,157,750	7,300,200
57	Railroads	461,000	226,000	375,000
58	Roads and bridges	1,260,000	594,000	857,000
59	Earth embankments	1,383,300	....	19,000
		$165,884,430	$176,368,990	$175,198,960
	Engineering and ordinary contingencies	16,588,443	17,636,899	17,519,896
	Interest during construction	27,370,931	17,460,530	22,162,668
	Total	$209,843,804	$211,466,419	$214,881,524

ST. LAWRENCE DEVELOPMENT—Estimate No. 2

November 10, 1921

COMPARATIVE ESTIMATES OF SCHEME "A" SINGLE DEVELOPMENT AT BARNHART ISLAND; SCHEME "B" DOUBLE DEVELOPMENT AT MORRISBURG AND BARNHART ISLAND; AND SCHEME "C" DOUBLE DEVELOPMENT AT CRYSLER ISLAND AND BARNHART ISLAND, SHOWING APPORTIONMENT OF COSTS FOR NAVIGATION AND POWER

No.	Item	Scheme "A"		Scheme "B"		Scheme "C"	
		Navigation	Power	Navigation	Power	Navigation	Power
1	Channel improvements, South Galops	$4,981,700	$4,981,700	$4,981,700	$4,981,700	$4,981,700	$4,981,700
2	Channel improvements, North Galops	1,945,650	1,945,650	1,945,650	1,945,650	1,945,650	1,945,650
3	Unwatering Galops channels	627,500	627,500	627,500	627,500	627,500	627,500
4	Channel improvements, Lotus island to Leishman Point	1,734,050	1,734,050	1,572,460	1,572,450	1,572,460	1,572,450
5	Excavation on and near Ogden island except for lock and navigation channel	860,500	860,500	587,770	587,770		
6	Lock at Ogden island	3,117,310					
7	Lock at Mariatown			3,136,250			
8	Excavation above and below lock	330,970		2,315,230			
9	Dam at Ogden island	1,080,900	1,080,900	1,182,115	1,182,115		
10	Earth embankments at dam	100,430	100,430	254,510	254,510		
11	Unwatering dam site	600,000	600,000	550,000	550,000		
12	Dam in diversion channel, Ogden island	295,500	295,500				
13	Dam in Little river, south of Ogden island	229,350	229,350				
14	Cut through Murphy Point and dam				1,500,230		
15	Power house opposite Morrisburg				46,940,000		
16	Unwatering power-house site				675,000		
17	Bridge for railway spur above lock			122,500	122,500		
18	Channel improvements for navigation, Clark island to Weaver Point	669,250		2,300,775	2,300,775	75,175	75,175
19	Canal and lock at Weaver Point					6,045,400	
20	Bridge for railway spur above lock					122,500	122,500

21 Earth embankments at lock	....	....	....	....	137,085	137,085
22 Power house at Crysler island	....	....	....	....	....	45,470,000
23 Ice sluiceways	....	....	....	....	....	1,004,240
24 Earth embankments, Crysler island and American shore	....	....	....	....	359,485	359,485
25 Main dam, sluiceway and bulkhead sections	....	....	....	....	1,905,220	1,905,220
26 Unwatering dam site and power-house site	....	....	....	....	1,550,000	1,550,000
27 Channel improvements for navigation, Weaver Point to Guard lock	200,250	....	1,511,020	1,511,020	1,511,020	1,511,020
28 Guard gate, retaining wall and weir at head of Sheek island	2,278,670	....	....	....	....	....
29 Lock at Moulinette	4,158,110	....	....	....	....	....
30 Weir north of Lock 8	266,040	....	....	....	....	....
31 Earth embankment north of Lock 8	339,710	....	....	....	....	....
32 Navigation channel below Moulinette	3,864,650	....	....	....	....	....
33 Navigation channel, locks and embankments, Sheek island to Paper Mill lock	....	....	9,599,520	....	9,599,520	....
34 Paper Mill lock and entrance piers	4,154,740	....	4,154,740	....	4,154,740	....
35 Dam at upper end of Lock 7	459,390	....	459,390	....	459,390	....
36 N.Y.C. bridge and diversion	315,000	....	315,000	....	315,000	....
37 Electric Railway diversion and lift bridge	100,000	....	100,000	....	100,000	....
38 Culvert to supply water to Mills	142,000	....	142,000	....	142,000	....
39 Power house at head of South Sault	....	5,527,140	....	....	....	....
40 Works in South Sault	1,355,410	1,355,410	1,101,270	1,101,270	1,101,270	1,101,270
41 Hooples Creek diversion and dam	509,455	509,455	....	....	....	....
42 Diversion channel and dam on Long Sault island	1,256,725	1,256,725	1,093,615	1,093,615	1,093,615	1,093,615
43 Main Long Sault dam	4,498,950	4,498,950	2,692,575	2,692,575	2,692,575	2,692,575
44 Ice diverter at head of Barnhart island	....	139,000	....	109,400	....	109,400
45 Excavation between Barnhart and Sheek islands	....	....	....	2,042,810	....	2,042,810
46 Retaining wall from north end of power house to Sheek island	1,500,000	9,084,620	....	....	....	....
47 Core in fill, power house to canal bank	....	....	....	654,430	....	654,430
48 Barnhart island power houses	....	62,383,200	....	46,090,000	....	46,090,000
49 Ice sluiceways between power houses	....	2,730,400	....	2,139,970	....	2,139,970
50 Retaining wall at south end of power house	....	405,600	....	....	....	....

ST. LAWRENCE DEVELOPMENT—Estimate No. 2 *(Continued)*

No.	Item	Scheme "A"		Scheme "B"		Scheme "C"	
		Navigation	Power	Navigation	Power	Navigation	Power
51	Forebay excavation	....	895,150	....	1,863,940	....	1,863,940
52	Tailrace excavation	....	2,195,870	....	2,195,870	....	2,195,870
53	Unwatering power-house site	....	370,000	....	370,000	....	370,000
54	Excavation, Crab Island shoal	....	423,550	....	423,550	....	423,550
55	Channel improvements below canal entrance	4,117,000	....	4,117,000	....	4,117,000	....
56	Land damages	6,230,000	6,230,000	2,578,875	2,578,875	3,650,100	3,650,100
57	Raising G. T. railway	230,500	230,500	113,000	113,000	187,500	187,500
58	Roads and bridges	630,000	630,000	297,000	297,000	428,500	428,500
59	Earth embankments	691,650	691,650	....	....	9,500	9,500
		$53,871,630	$112,012,800	$47,851,465	$128,517,525	$48,883,905	$126,315,055
	Engineering and ordinary contingencies	5,387,163	11,201,280	4,785,147	12,851,752	4,888,390	12,631,505
	Interest during construction	8,888,819	18,482,112	4,737,295	12,723,235	6,183,814	15,978,855
		$68,147,612	$141,696,192	$57,373,907	$154,092,512	$59,956,109	$154,925,415
	Capital cost per electrical horsepower, 24-hour power	....	$95	....	$96	....	$95

ST. LAWRENCE DEVELOPMENT—Estimate No. 3

November 10, 1921

INITIAL SCHEME "A" DEVELOPMENT WITH NAVIGATION WORKS COMPLETE

NORTHERLY POWER HOUSE ONLY, TO BE BUILT AT BARNHART ISLAND WITH ONE ICE SLUICE AT EACH END. TWENTY-SEVEN UNITS INSTALLED

735,000 ELECTRICAL HORSEPOWER OF 24-HOUR POWER

Item	Navigation	Power
Channel improvements South Galops	$4,981,700	$4,981,700
Channel improvements North Galops	1,945,650	1,945,650
Unwatering Galops channels	627,500	627,500
Channel improvements Lotus island to Leishman Point	1,734,050	1,734,050
Excavation on and near Ogden island except for lock and navigation channel	860,500	860,500
Lock at Ogden island	3,117,310	....
Excavation above and below lock	330,970	....
Dam at Ogden island	1,080,900	1,080,900
Earth embankments at dam	100,430	100,430
Unwatering dam site	600,000	600,000
Diversion channel and dam, Ogden island	295,500	295,500
Dam in Little river, south of Ogden island	229,350	229,350
Channel improvements for navigation, Clark island to Weaver Point	669,520	....
Channel improvements for navigation, Weaver Point to guard lock	200,250	....
Guard gate, retaining wall and weir at head of Sheek island	2,278,670	....
Lock at Moulinette	4,158,110	....
Weir north of Lock 8	266,040	....
Earth embankment north of Lock 8	339,710	....
Navigation channel below Moulinette	3,864,650	....
Paper Mill lock and entrance piers	4,154,740	....
Dam at upper end of Lock 7	459,390	....
N.Y.C. bridge and diversion	315,000	....
Electric railway diversion and lift bridge	100,000	....
Culvert to supply water to mills	142,000	....
Works in South Sault	1,555,410	1,555,410
Hooples Creek diversion and dam	509,455	509,455
Diversion channel and dam on Long Sault island	1,256,725	1,256,725
Main Long Sault dam	4,498,950	4,498,950
Ice diverter, cribs and booms at head of Barnhart island	....	139,000
Retaining wall from north end of power house to Sheek island	1,500,000	9,084,620
Forebay excavation	....	447,580
Tailrace excavation	....	1,097,935
Unwatering power-house site	....	370,000
Channel improvements below canal entrance	4,117,000	....
Land damages	6,230,000	6,230,000

ST. LAWRENCE DEVELOPMENT—Estimate No. 3 (*Continued*)

Item	Navigation	Power
Railroads	230,500	230,500
Roads and bridges	630,000	630,000
Power house at Barnhart island	....	32,418,000
Ice sluices	....	612,540
Earth embankments	691,650	691,650
Core wall embankment, south end of power house to 240 contour	....	1,619,930
	$54,071,630	$73,848,235
Engineering and ordinary contingencies	5,407,163	7,384,824
Interest during construction	8,921,819	12,184,959
Total	$68,400,612	$93,418,018
Capital cost per electrical horsepower 24-hour power	....	$127

Note: The cost per electrical horsepower for any load factor may be obtained by multiplying the above cost per horsepower by that load factor.

ST. LAWRENCE DEVELOPMENT—Estimate No. 4

November 10, 1921

INITIAL SCHEME "B" DEVELOPMENT WITH NAVIGATION WORKS COMPLETE

POWER HOUSE AT MORRISBURG. NAVIGATION WORKS COMPLETE, PRESCOTT TO CORNWALL
600,000 ELECTRICAL HORSEPOWER OF 24-HOUR POWER

Item	Navigation	Power
Channel improvements to Leishman Point	$9,127,300	$9,127,300
Excavation on and near Ogden island except for lock and navigation channel	587,770	587,770
Lock at Mariatown	3,136,250	....
Excavation above and below lock	2,315,230	....
Dam at Ogden island	1,182,115	1,182,115
Earth embankments at dam	254,510	254,510
Unwatering dam site	550,000	550,000
Cut through Murphy Point and dam	....	1,500,230
Power house opposite Morrisburg	....	46,940,000
Unwatering power-house site	....	675,000
Bridge for railway spur above lock	122,500	122,500
Channel improvements, Clark island to Weaver Point	4,601,550	....
Channel improvements, Weaver Point to Sheek island	3,022,040	....
Temporary rock-fill dam in Long Sault	240,000	....
Navigation works head of Sheek island to Paper Mill lock	9,599,520	....
Paper Mill lock and entrance piers	4,154,740	....
Dam at upper end of Lock No. 7	459,390	....
N.Y.C. bridge and diversion	315,000	....
Electric railway diversion and bridge	100,000	....
Culvert to supply water to mills	142,000	....
Channel improvements below canal entrance at Cornwall	4,117,000	....
Land damages	2,378,875	2,378,875
Raising G. T. railway	113,000	113,000
Roads and bridges	297,000	297,000
	$46,815,790	$63,728,300
Engineering and ordinary contingencies	4,681,579	6,372,830
Interest during construction	4,634,763	6,309,102
Total	$56,132,132	$76,410,232
Capital cost per electrical horsepower 24-hour power	....	$127

Note: The cost per electrical horsepower for any load factor may be obtained by multiplying the above cost per horsepower by that load factor.

ST. LAWRENCE DEVELOPMENT—Estimate No. 5

November 10, 1921

INITIAL SCHEME "C" DEVELOPMENT WITH NAVIGATION WORKS COMPLETE

Power House at Crysler Island. Navigation Works Complete, Prescott to Cornwall
635,000 Electrical Horsepower of 24-Hour Power

Item	Navigation	Power
Channel improvements to Leishman Point	$9,127,300	$9,127,300
Channel improvements to Crysler island	75,175	75,175
Canal and lock at Weaver Point	6,045,400	....
Bridge for railway spur above lock	122,500	122,500
Earth embankments at lock	137,085	137,085
Power house at Crysler island	....	45,470,000
Ice sluiceways	....	1,004,240
Main dam	1,905,220	1,905,220
Earth embankments at dam	339,485	339,485
Unwatering dam site and power-house site	1,550,000	1,550,000
Channel improvements to Sheek island	3,022,040	....
Navigation works head of Sheek island to Paper Mill lock	9,599,520	....
Paper Mill lock and entrance piers	4,154,740	....
Dam at upper end of Lock No. 7	459,390	....
N.Y.C. bridge and diversion	315,000	....
Electric railway diversion and bridge	100,000	....
Culvert to supply water to mills	142,000	....
Channel improvements below canal entrance at Cornwall	4,117,000	....
Land damages	3,650,100	3,650,100
Raising G.T. railway	187,500	187,500
Roads and bridges	428,500	428,500
Earth embankments	9,500	9,500
	$45,487,455	$64,006,605
Engineering and ordinary contingencies	4,548,746	6,400,660
Interest during construction	5,754,163	8,096,835
Total	$55,790,364	$78,504,100
Capital cost per electrical horsepower, 24-hour power	....	$124

Note: The cost per electrical horsepower for any load factor may be obtained by multiplying the above cost per horsepower by that load factor.

ST. LAWRENCE DEVELOPMENT—Estimate No. 6

November 10, 1921

INITIAL SCHEME "A" DEVELOPMENT WITH FOURTEEN-FOOT NAVIGATION

Without River Improvements, and with Head of Long Sault Raised to Elevation 208 Only. Present Depth of Navigation 14 Ft. Maintained. Head Available at Barnhart Island will be About 48 Ft. Turbines Designed for 74.5 Ft. Head will Develop at 48 Ft., only 40 per cent of Their Normal Output

585,000 Electrical Horsepower of 24-Hour Power

Item	Cost
Raising bank and first lock at Cornwall canal to stand water level of 210..	$136,000
Dam at head of South Sault	1,943,650
Addition to above south end	250,000
Diversion channel and dam Long Sault island	2,418,722
Main Long Sault dam	8,018,300
Ice diverter cribs, etc	109,400
Excavation between Sheek and Barnhart islands	2,042,810
Retaining wall power houses to Sheek island	10,176,620
Barnhart Island power houses	62,383,200
Ice sluiceways	2,730,400
Retaining wall, south end of power house	395,760
Forebay excavation	1,863,940
Tailrace excavation	2,195,870
Unwatering power-house site	370,000
Land damages	12,460,000
	$107,494,672
Engineering and ordinary contingencies	10,749,467
Interest during construction	17,736,621
Total	$135,980,760
Capital cost per electrical horsepower, 24-hour power	$232

Note: The cost per electrical horsepower for any load factor may be obtained by multiplying the above cost per horsepower by that load factor.

ST. LAWRENCE DEVELOPMENT—Estimate No. 7

November 10, 1921

INITIAL SCHEME "B" DEVELOPMENT WITH FOURTEEN-FOOT NAVIGATION

POWER HOUSE AT MORRISBURG. ONLY SUFFICIENT WORK DONE IN GALOPS CHANNELS TO PREVENT RAISING LAKE ONTARIO LEVEL. FOURTEEN-FOOT NAVIGATION PROVIDED BY THE USE OF THE PRESENT LOCK 23 AND THE PROVISION OF A NEW LOCK WITH 13-FT. LIFT AT THE MORRISBURG DAM

600,000 ELECTRICAL HORSEPOWER OF 24-HOUR POWER

Item	Cost
Channel improvements at Galops	$3,579,750
Excavation on and near Ogden island	1,175,540
Thirteen-foot lock at dam	875,000
Dam at Ogden island	2,364,230
Earth embankment at dam	509,020
Unwatering dam site	1,100,000
Cut through Murphy Point and dam	1,500,230
Power house opposite Morrisburg	46,940,000
Unwatering power-house site	675,000
Land damages	3,492,000
Railroads	226,000
Roads and bridges	312,000
	$62,738,770
Engineering and ordinary contingencies	6,273,877
Interest during construction	6,211,138
Total	$75,223,785
Capital cost per electrical horsepower, 24-hour power	$125

Note: The cost per electrical horsepower for any load factor may be obtained by multiplying the above cost per horsepower by that load factor.

ST. LAWRENCE DEVELOPMENT—Estimate No. 8

November 10, 1921

INITIAL SCHEME "C" DEVELOPMENT WITH FOURTEEN-FOOT NAVIGATION

CRYSLER ISLAND POWER HOUSE AND DAM BUILT FIRST WITH A LOCK ON CRYSLER ISLAND FOR 14-FT. NAVIGATION. ONLY SUFFICIENT CHANNEL IMPROVEMENT TO BE MADE IN THE GALOPS CHANNELS TO PERMIT RAISING THE HEADWATER AT CRYSLER ISLAND WITHOUT AFFECTING LAKE ONTARIO

635,000 ELECTRICAL HORSEPOWER OF 24-HOUR POWER

Item	Cost
Channel improvements at Galops island	$3,579,750
Lock at Crysler island for 14-ft. navigation	950,000
Power house at Crysler island	45,470,000
Ice sluiceways	1,024,240
Earth embankments, Crysler island and American shore	718,970
Main dam sluiceways and bulkhead section	3,810,440
Unwatering	3,100,000
Railroads	375,000
Roads and bridges	660,000
Land and property damage	5,513,220
	$65,210,620
Engineering and ordinary contingencies	6,521,062
Interest during construction	8,249,144
Total	$79,980,826
Capital cost per electrical horsepower, 24-hour power	$126

Note: The cost per electrical horsepower for any load factor may be obtained by multiplying the above cost per horsepower by that load factor.

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PLANS

ACCOMPANYING

ENGINEERING REPORT

BY THE

HYDRO-ELECTRIC POWER COMMISSION

OF ONTARIO

SUBMITTED TO THE

INTERNATIONAL JOINT COMMISSION

RESPECTING

THE PROPOSAL TO DEVELOP

THE

ST. LAWRENCE RIVER

1921

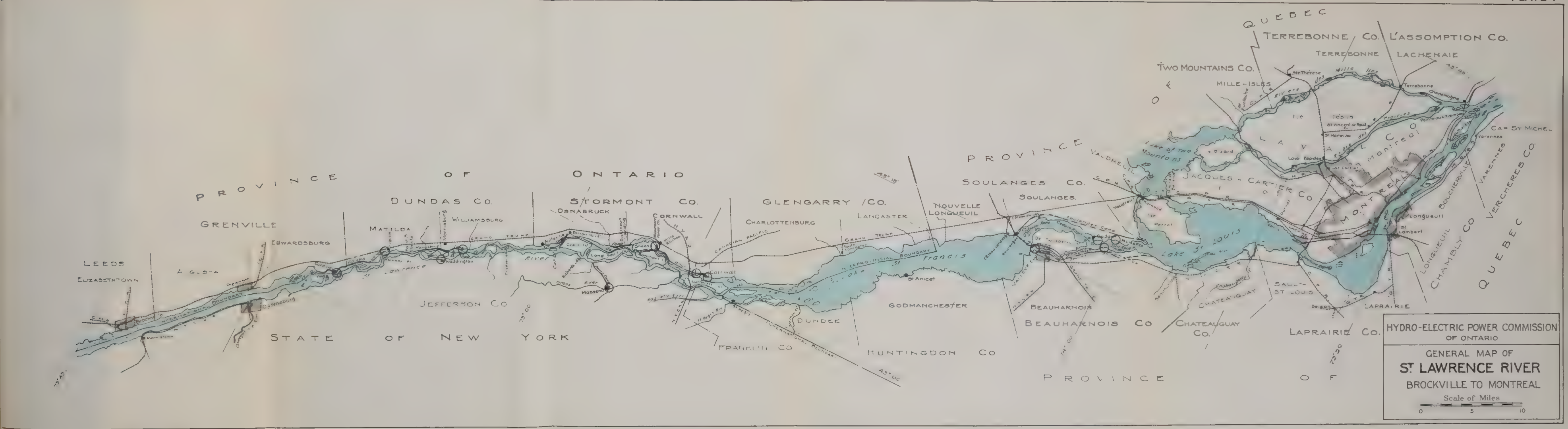
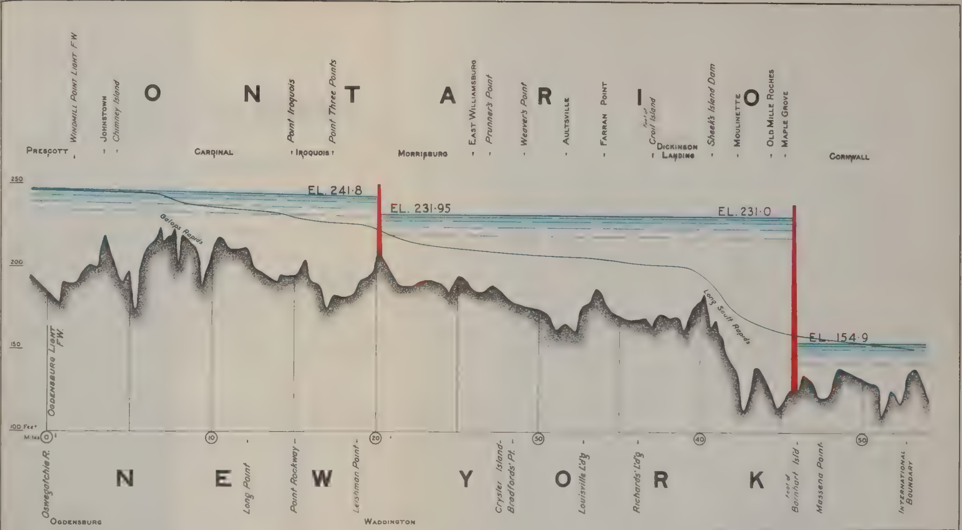

QUEBEC
TERREBONNE CO.
L'ASSOMPTION CO.
TERREBONNE
LACHENAIE
TWO MOUNTAINS CO.
MILLE-ISLES
PROVINCE OF ONTARIO
DUNDAS CO.
STORMONT CO.
GLENGARRY CO.
GRENVILLE
EDWARDSBURG
LEEDS
ELIZABETHTOWN
MATILDA
WILLIAMSBURG
OSNABRUCK
CORNWALL
CHARLOTTENBURG
LANCASTER
NOUVELLE LONGUEUIL
SOULANGES CO.
SOULANGES
PROVINCE
VAUDREUIL
JACQUES-CARTIER CO.
MONTREAL
Lake St. Louis
Lake of Two Mountains
Lake St. Francis
St. Anicet
GODMANCHESTER
BEAUHARNOIS
BEAUHARNOIS CO
CHATEAUGUAY
CHATEAUGUAY CO.
SAULT-ST. LOUIS
LAPRAIRIE
LAPRAIRIE CO.
CAP ST. MICHEL
VARENNES
BOUCHERVILLE
LONGUEUIL
CHAMBLY CO
VERCHERES CO
QUEBEC
Longueuil
Terrebonne
Cornwall
Massena
Waddington
Ogdensburg
JEFFERSON CO
STATE OF NEW YORK
FRANKLIN CO
DUNDEE
HUNTINGDON CO
PROVINCE OF
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
GENERAL MAP OF
ST. LAWRENCE RIVER
BROCKVILLE TO MONTREAL
Scale of Miles
0 5 10

PLATE II

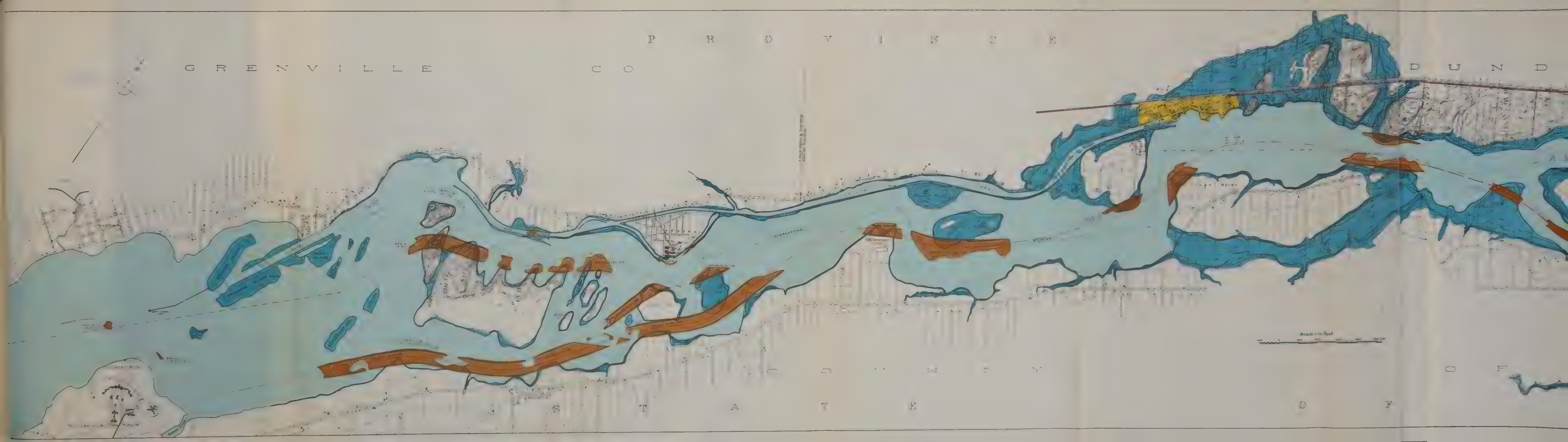


HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
ST LAWRENCE RIVER

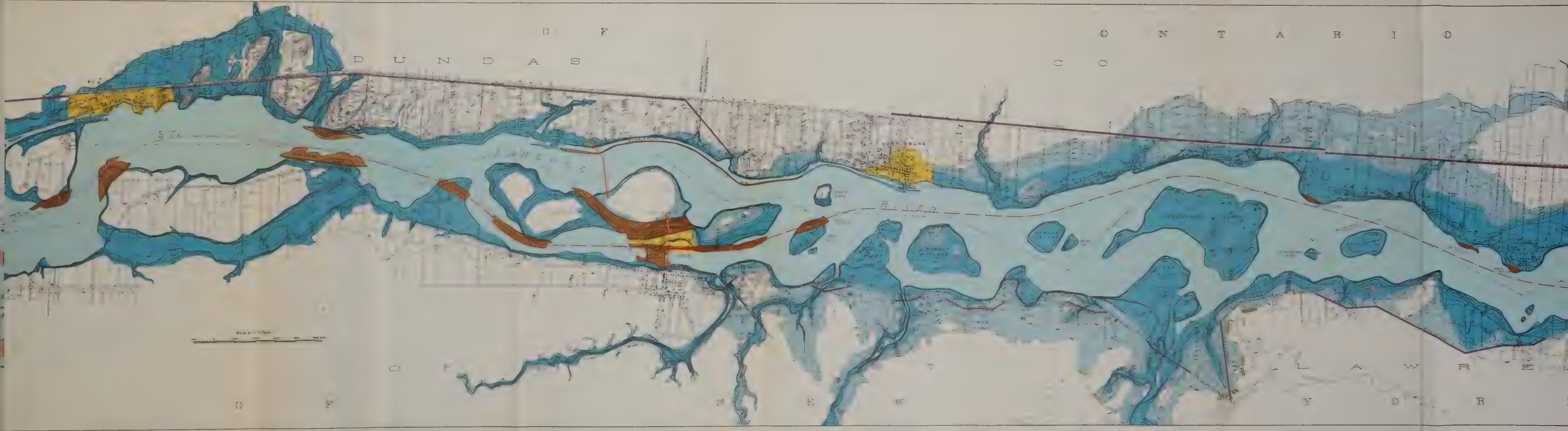
PROJECT FOR COMBINED DEVELOPMENT OF THE RIVER
FOR POWER AND NAVIGATION FROM
PRESCOTT TO CORNWALL

SCHEME "A"

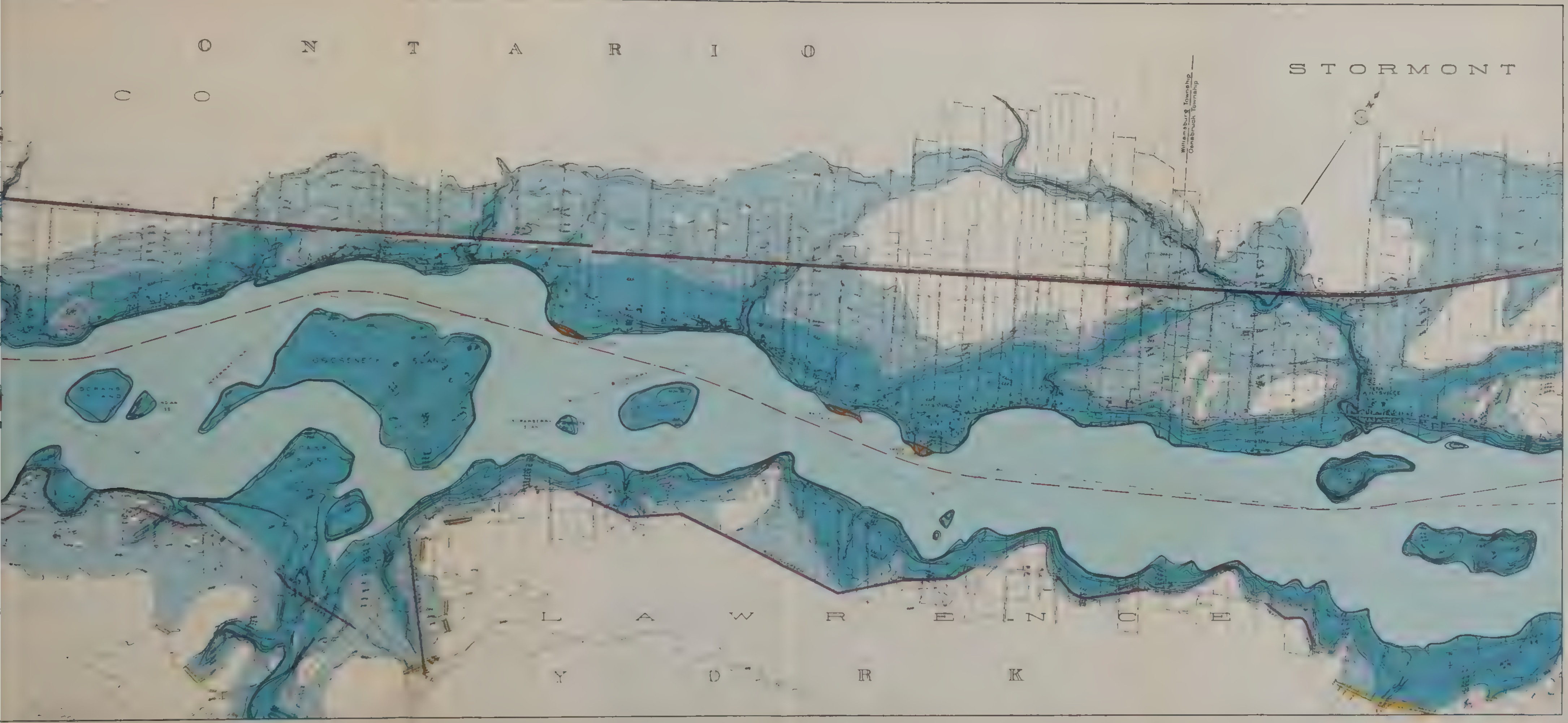
SINGLE-STAGE DEVELOPMENT OF THE WHOLE
AVAILABLE POWER HEAD AT BARNHART ISLAND.



P R O V I N C E
G R E N V I L L E
C O
D U N D
S T A T E
O F
Scale – in feet



D U N D A S
O N T A R I O
C O
L A W R E



HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO

S^T LAWRENCE RIVER

PROJECT FOR COMBINED DEVELOPMENT OF THE RIVER
FOR POWER AND NAVIGATION FROM
PRESCOTT TO CORNWALL

SCHEME "A"

SINGLE-STAGE DEVELOPMENT OF THE WHOLE AVAILABLE
POWER HEAD AT BARNHART ISLAND
UPPER SECTION

LEGEND

PRESENT WATER AREA
AREA TO BE FLOODED
ADDITIONAL FLOODED AREA
EXCAVATION FOR NAVIGATION
EXCAVATION FOR POWER DEVELOPMENT
EMBANKMENTS AND FILLS
CONCRETE STRUCTURES
COURSE OF NAVIGATION
NEW ROADS

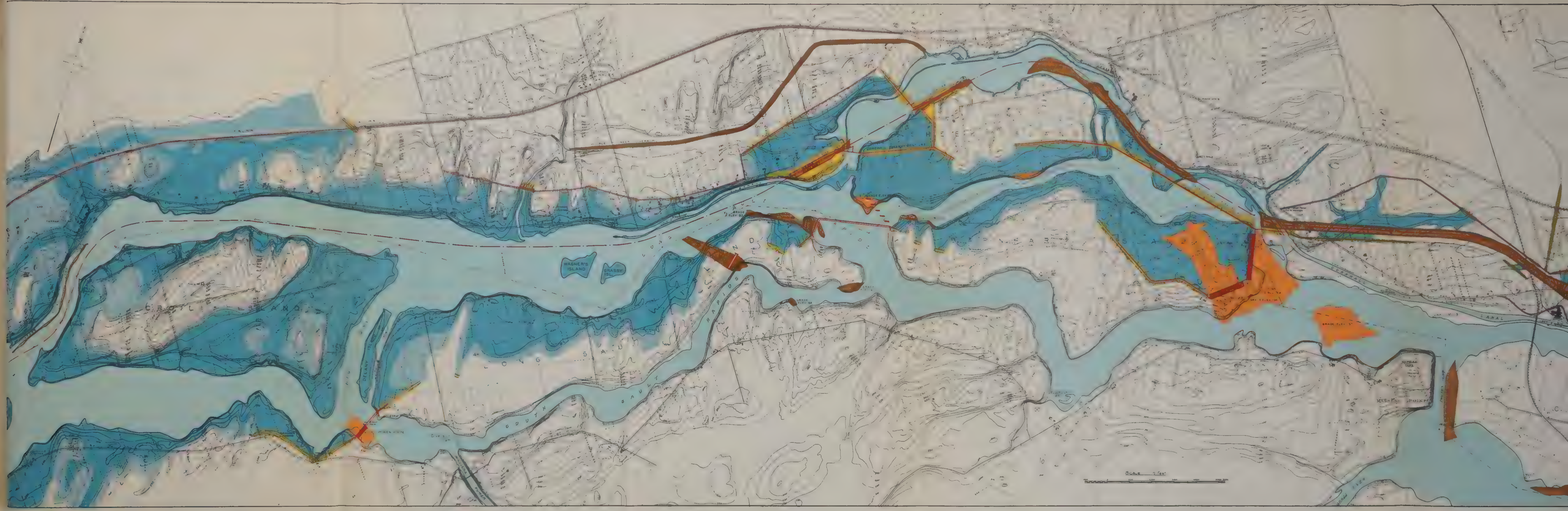

WAGNER'S ISLAND
GRASSY ISL.
RAPIDS

PLATE IV

HYDRO-ELECTRIC POWER COMMISSION

OF ONTARIO

St LAWRENCE RIVER

PROJECT FOR COMBINED DEVELOPMENT OF THE RIVER FOR POWER AND NAVIGATION FROM PRESCOTT TO CORNWALL

SCHEME "A"

SINGLE-STAGE DEVELOPMENT OF THE WHOLE AVAILABLE POWER HEAD AT BARNHART ISLAND

(LOWER SECTION)

LEGEND

PRESENT WATER AREA

AREA TO BE FLOODED

ADDITIONAL FLOODED AREA

EXCAVATION FOR NAVIGATION

EXCAVATION FOR POWER DEVELOPMENT

EMBANKMENTS AND FILLS

CONCRETE STRUCTURES

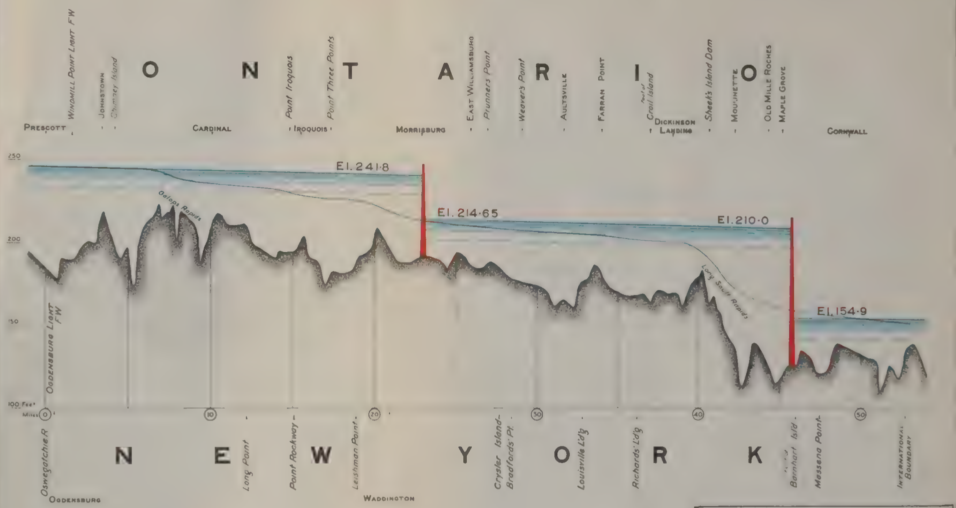
COURSE OF NAVIGATION

NEW ROADS

F A Gaby
Chief Engineer

H G Acres
Hydraulic Engineer

R S Lea
Consulting Engineer

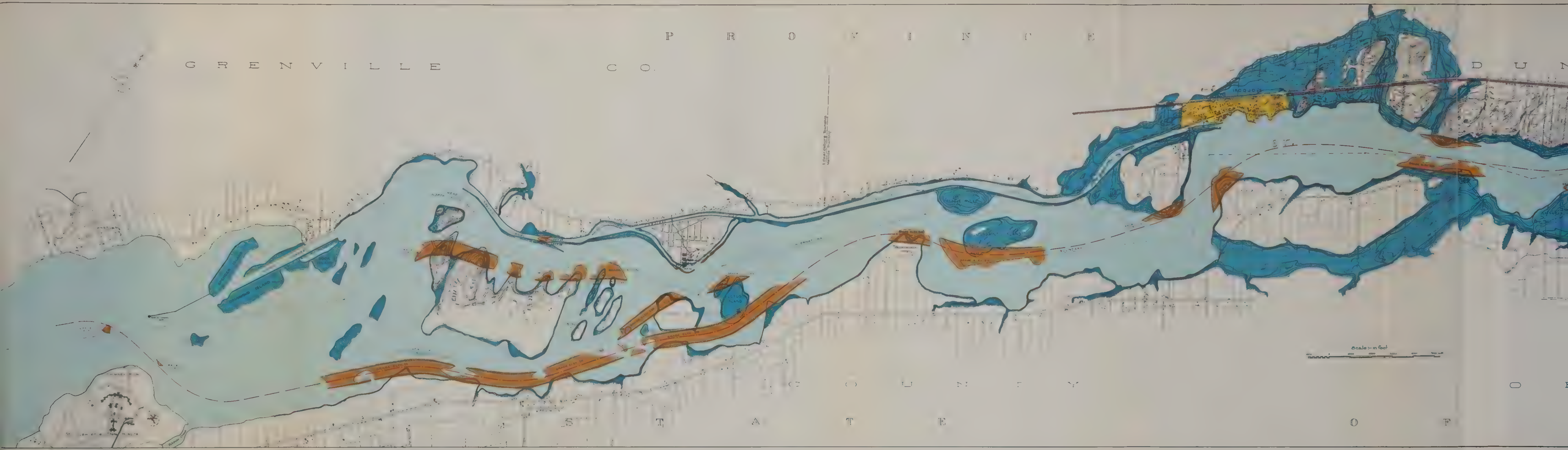


HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
ST LAWRENCE RIVER

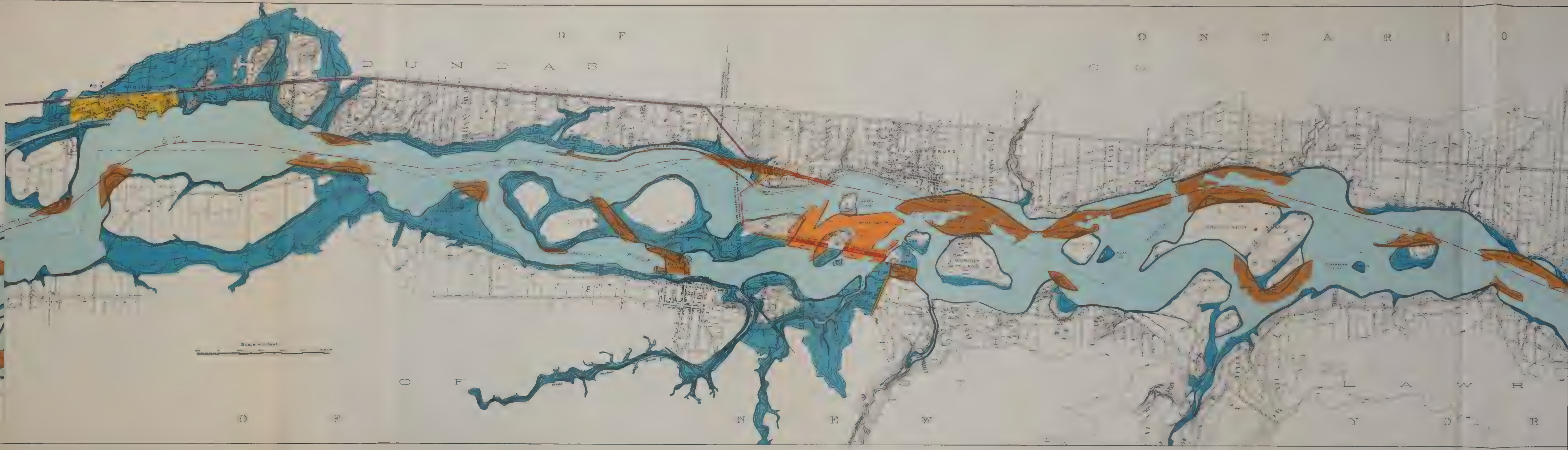
PROJECT FOR COMBINED DEVELOPMENT OF THE RIVER
FOR POWER AND NAVIGATION FROM
PRESCOTT TO CORNWALL

SCHEME "B"

TWO-STAGE DEVELOPMENT OF POWER
AT MORRISBURG AND BARNHART ISLAND



P R O V I N C E
G R E N V I L L E C O.
D U N
C O U N T Y
S T A T E O F
Scale - in feet



O F
D U N D A S
O N T A R I O
C O
O F
N E W
S T
L A W R

HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO

ST LAWRENCE RIVER

PROJECT FOR COMBINED DEVELOPMENT OF THE RIVER FOR POWER AND NAVIGATION FROM PRESCOTT TO CORNWALL

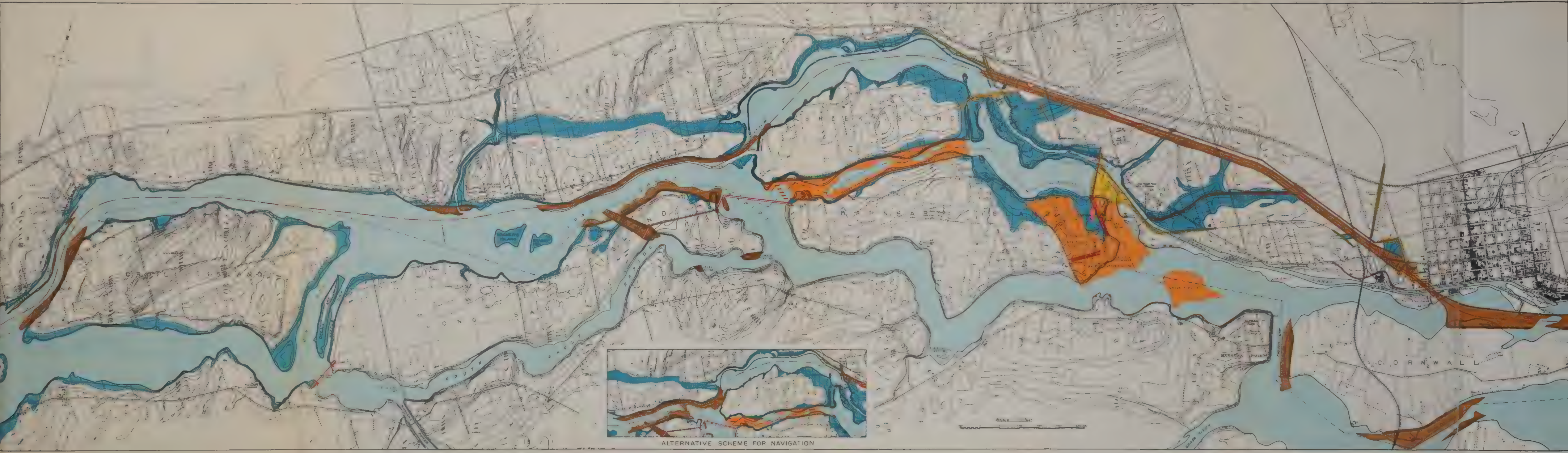
SCHEME "B"

TWO-STAGE DEVELOPMENT OF POWER AT MORRISBURG AND BARNHART ISLAND
(UPPER SECTION)

LEGEND

- PRESENT WATER AREA
- AREA TO BE FLOODED
- EXCAVATION FOR NAVIGATION
- EXCAVATION FOR POWER DEVELOPMENT
- EMBANKMENTS AND FILLS
- CONCRETE STRUCTURES
- COURSE OF NAVIGATION
- NEW ROADS

F. A. Gaby
Chief Engineer
H. G. Acres
Hydraulic Engineer
R. S. Lea
Consulting Engineer


CORNWALL
ALTERNATIVE SCHEME FOR NAVIGATION

HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO

S^T LAWRENCE RIVER

PROJECT FOR COMBINED DEVELOPMENT OF THE RIVER FOR POWER AND NAVIGATION FROM PRESCOTT TO CORNWALL

SCHEME "B"

TWO-STAGE DEVELOPMENT OF POWER AT MORRISBURG AND BARNHART ISLAND
LOWER SECTION.

LEGEND

PRESENT WATER AREA
AREA TO BE FLOODED
EXCAVATION FOR NAVIGATION
EXCAVATION FOR POWER DEVELOPMENT
EMBANKMENTS AND FILLS
CONCRETE STRUCTURES
COURSE OF NAVIGATION
NEW ROADS

F A Gaby
Chief Engineer
H G Acres
Hydraulic Engineer
R S Lea
Consulting Engineer

PLATE VIII

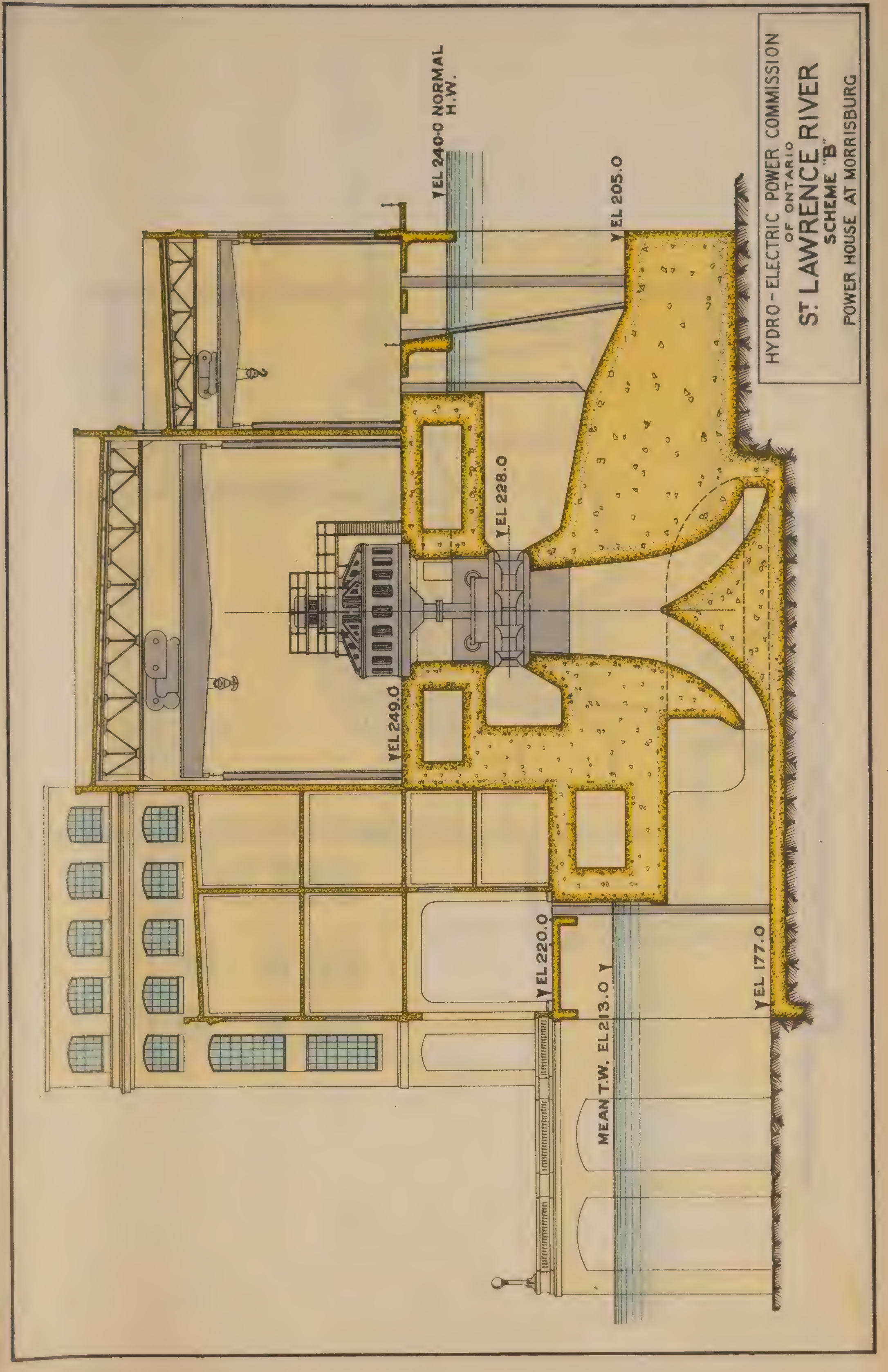
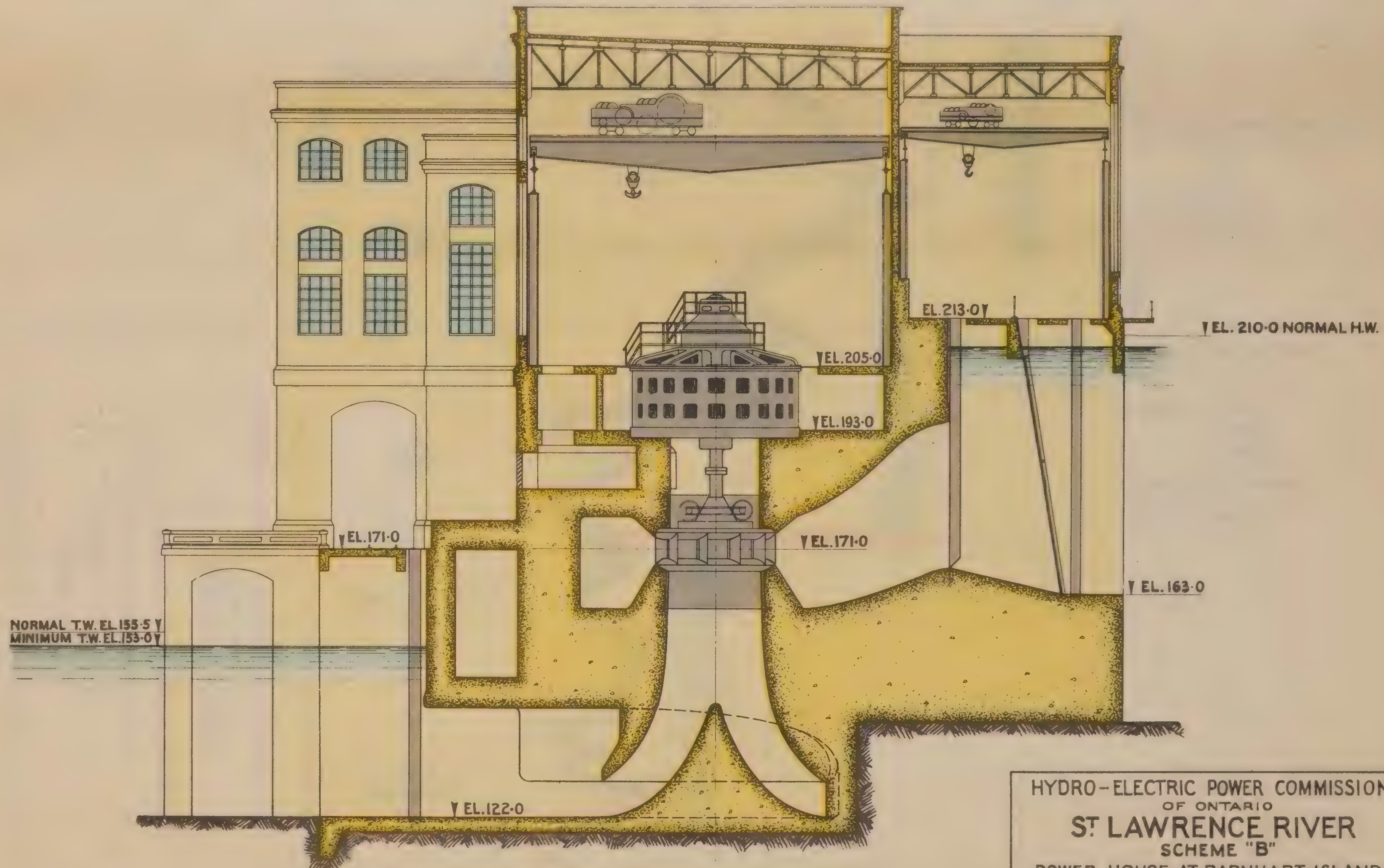
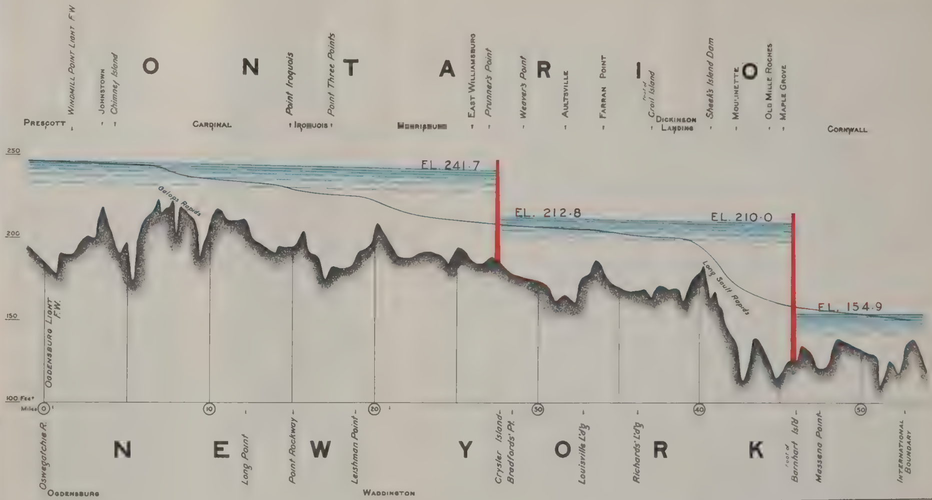

HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
St. LAWRENCE RIVER
SCHEME "B"
POWER HOUSE AT MORRISBURG
EL 240-0 NORMAL H.W.
EL 205.0
EL 228.0
EL 249.0
EL 220.0
EL 177.0
MEAN T.W. EL 213.0

PLATE IX



HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
ST LAWRENCE RIVER
SCHEME "B"
POWER HOUSE AT BARNHART ISLAND

PLATE X

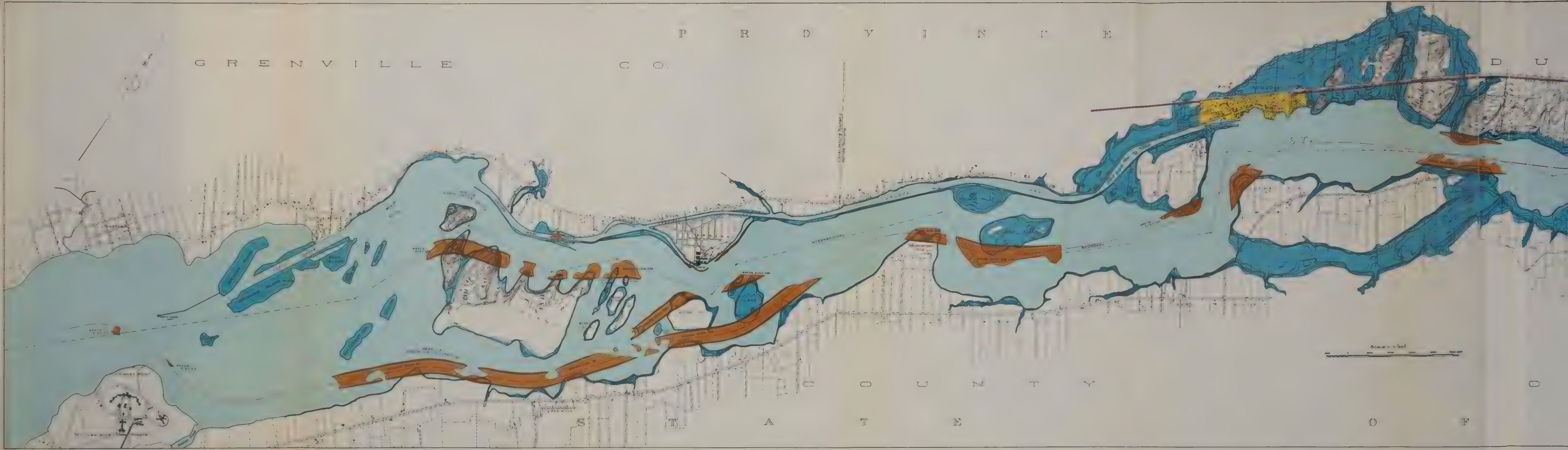


HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
ST. LAWRENCE RIVER

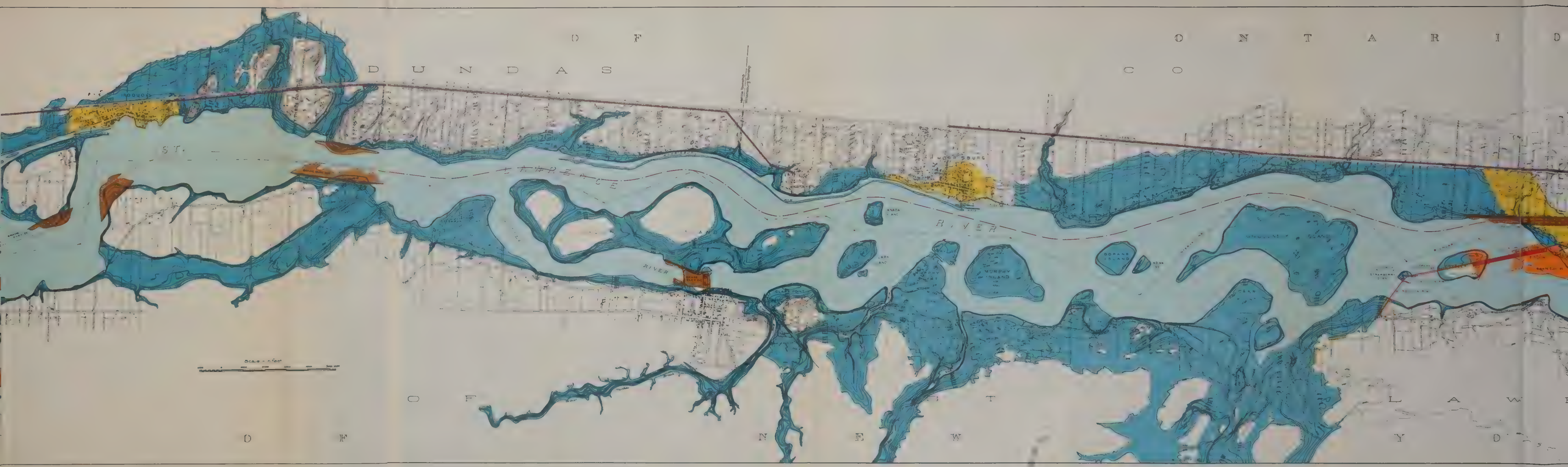
Project for Combined Development of the River
for Power and Navigation from
Prescott to Cornwall

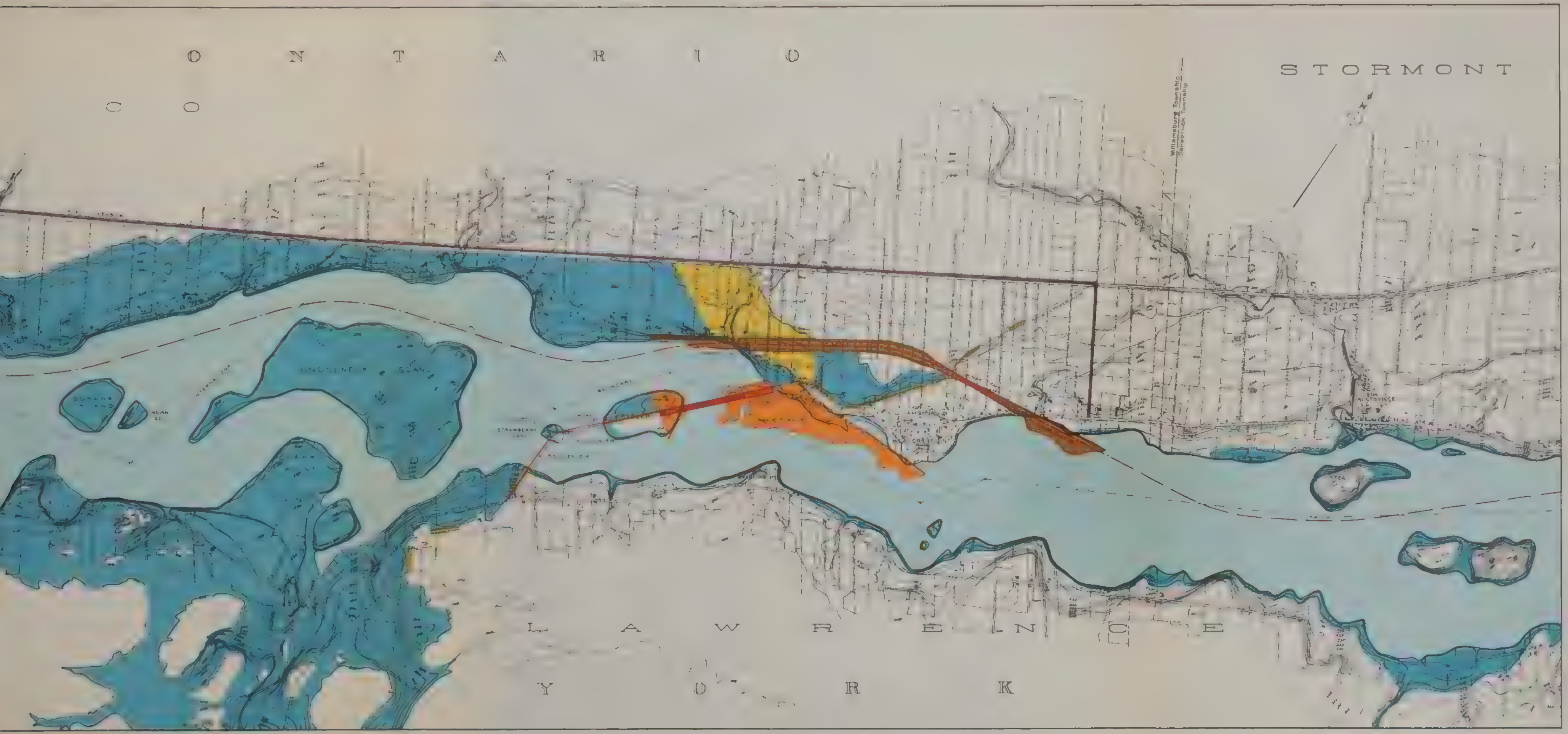
SCHEME "C"

Two-Stage Development of Power
at Crysler and Barnhart Islands



PROVINCE
GRENVILLE CO.
DU
COUNTY
STATE OF


O F
D U N D A S
C O
O N T A R I O
ST.
LAWRENCE
RIVER
RIVER



HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO

S^T LAWRENCE RIVER

PROJECT FOR COMBINED DEVELOPMENT OF THE RIVER
FOR POWER AND NAVIGATION FROM
PRESCOTT TO CORNWALL

SCHEME "C"

TWO-STAGE DEVELOPMENT OF POWER AT CRYSLER'S
ISLAND AND BARNHART ISLAND
UPPER SECTION

LEGEND

- PRESENT WATER AREA
- AREA TO BE FLOODED
- EXCAVATION FOR NAVIGATION
- EXCAVATION FOR POWER DEVELOPMENT
- EMBANKMENTS AND FILLS
- CONCRETE STRUCTURES
- COURSE OF NAVIGATION
- NEW ROADS

F. A. Gaby
Chief Engineer
H. G. Acres
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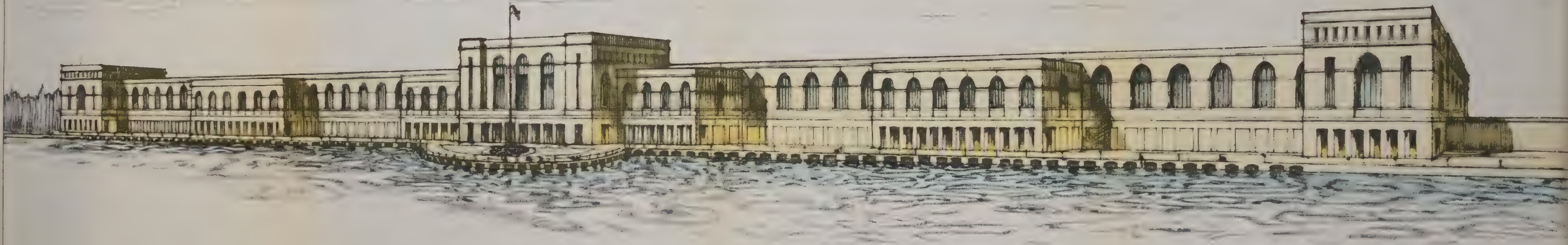
R. S. Lea
Consulting Engineer



HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
ST. LAWRENCE RIVER
SCHEME "B"
CANADIAN POWER HOUSE AT MORRISBURG


HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
PRESENT TRANSMISSION SYSTEMS
IN
ONTARIO AND QUEBEC, CANADA
AND
NORTH-EASTERN UNITED STATES
ALSO
PROPOSED NEW TRUNK LINES
(TENTATIVE MAP)
LEGEND
1 Existing Trunk Lines
2 Existing Transmission Lines
3 Proposed Trunk Lines
4 Proposed Lines Super Power Survey
NOTE · Transmission Lines shown are 12,000 volts and greater, and are both 25 and 60 cycle lines. Lines on this Map show routes only. Several circuits may exist where such routes are indicated
Scale of Miles
QUEBEC
SHAWINIGAN FALLS
THREE RIVERS
LAKE ST PETER
MONTREAL
OTTAWA
OTTAWA RIVER
CORNWALL
LAKE ST FRANCIS
PROPOSED ST LAWRENCE RIVER POWER PROJECT
MASSENA
LAKE CHAMPLAIN
KINGSTON
BELLEVILLE
TORONTO
LAKE ONTARIO
HAMILTON
QUEENSTON
NIAGARA FALLS
BUFFALO
ROCHESTER
SYRACUSE
UTICA
SCHENECTADY
ALBANY
BOSTON
PROVIDENCE
NEW YORK
PHILADELPHIA
WASHINGTON
SARNIA
LONDON
LAKE ST CLAIR
DETROIT
WINDSOR
CLEVELAND
LAKE ERIE
LAKE HURON
NORTH CHANNEL
GEORGIAN BAY
100 MILES
50 MILES
200 MILES
300 MILES
400 MILES
500 MILES